A LINEAR PROGRAMMING APPROACH FOR DETERMINING TRAVEL COST MINIMIZING ECSS TRAINING LOCATIONS

THESIS

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Abstract

The Department of Defense is currently operating in a fiscally constrained environment, and Air Force leaders are pressured to minimize spending while pursuing mission critical objectives. Personnel travel usurps a significant portion of the Air Force's annual operations and maintenance (O&M) budget each year, but receives little attention with respect to cost saving strategies. During the Air Force's implementation of the Expeditionary Combat Support System (ECSS), in which over 250,000 end-users will require training, it is vital that the Department determine the training locations that minimize costs incurred through personnel travel.

This thesis seeks to determine which potential ECSS training locations minimize travel costs, and thus reduce the system implementation's impact on the Air Force's constrained O&M budget. Airfare and per diem rates vary significantly depending on the travel destination, which naturally makes some potential training locations more costly, with respect to travel expenses, than others. In this research, the findings indicate that using a linear programming approach to identify the optimal ECSS training locations can potentially reduce overall travel costs from 80% to more than 130%. Furthermore, the research findings indicate that the Air Logistics Centers located at Robins, Hill, Hanscom and Tinker are likely to minimize travel costs for ECSS training if the supply, or training capacity, at these locations can satisfy the demand for training.

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This work is dedicated to my family.

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Jason Boerboom

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Chapter I: Introduction

Operating in a Fiscally Constrained Environment

In January of 2009, the Defense Business Board, submitted a report stressing that the Department of Defense, "is poised to enter a prolonged period of fiscal constraint with increasing deficits and competitive spending pressures;" a situation that the United States' recent economic hardships only exacerbates (Bayer, 2009:60). Over the past sixty years, there have been four periods of significant increase in the Department of Defense's budget authority; and to date, a considerable decrease in budget authority has immediately followed each period of growth. Figure 1 below depicts this trend and the forecasted decrease following the recent budgetary expansion during the Global War on Terrorism.

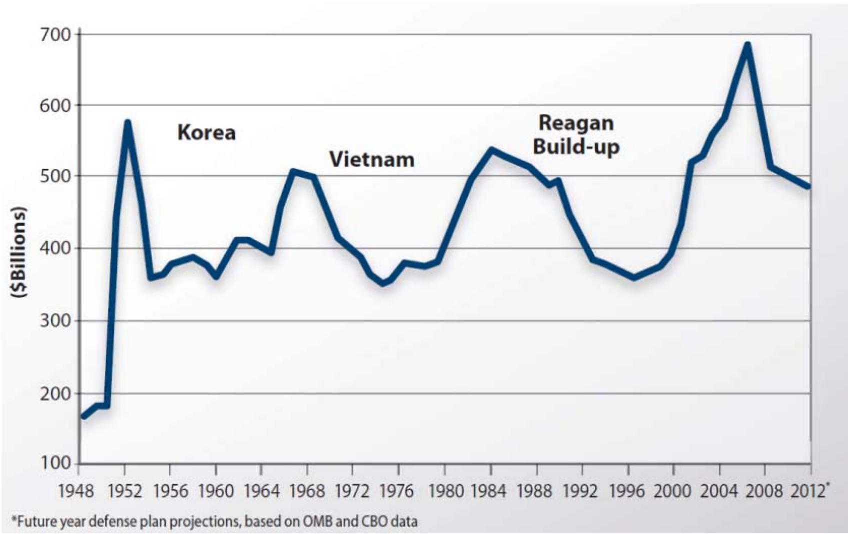


Figure 1: DoD Budget in Constant $FY09 (Bayer, 2009:61)

Shortly after the Defense Business Board's submission of the aforementioned report, in April of 2009, Defense Secretary Robert M. Gates addressed Air Force leaders attending the Air War College at Maxwell Air Force Base and emphasized the budgetary constraints facing the military. Specifically targeting the services' struggle to fund current requirements, Secretary Gates stated that, "it is the willingness of service heads ... to say ... 'You're going to find room in your base budget to take care of these problems,' and then seeing to it that it happens" (Baker, 2009). By placing this responsibility on the individual services, which have historically depended on supplemental funding from Congress in times of funding shortages, the Secretary of Defense has challenged military leaders to become more fiscally judicious in their decisions. Each service branch must be creative and explore all potential cost-saving possibilities in order to continue achieving their objectives amidst the impending decreases in budget authority.

The Operations and Maintenance (O&M) appropriation, which makes up more than 27 percent of the Air Force's proposed Fiscal Year 2010 (FY10) $160.5 billion budget, is a reasonable target for cost-saving opportunities for three reasons (Spencer, 2009: 4). First, O&M is a large appropriation that encompasses a wide range of Air Force activities, to include air operations, depot maintenance, facilities sustainment, training and education, base support, communication, recruiting, transportation, and mobilization (Department, 2009:i). Second, despite the potential for savings across many of its diverse activities, the U.S. Government Accountability Office, in a 2000 report, noted that O&M has failed to receive the scrutiny necessary to make dramatic cost reducing changes (GAO, 2000). Finally, O&M, because of the rapid rate of its budgetary

expansion over the past decade exceeded those of other appropriations, is likely to suffer dramatic reductions in the near future. The charts below illustrate this point. Figure 2 shows the Department of Defense's budget authority, by appropriation, with a significant O&M decrease forecasted after 2008.

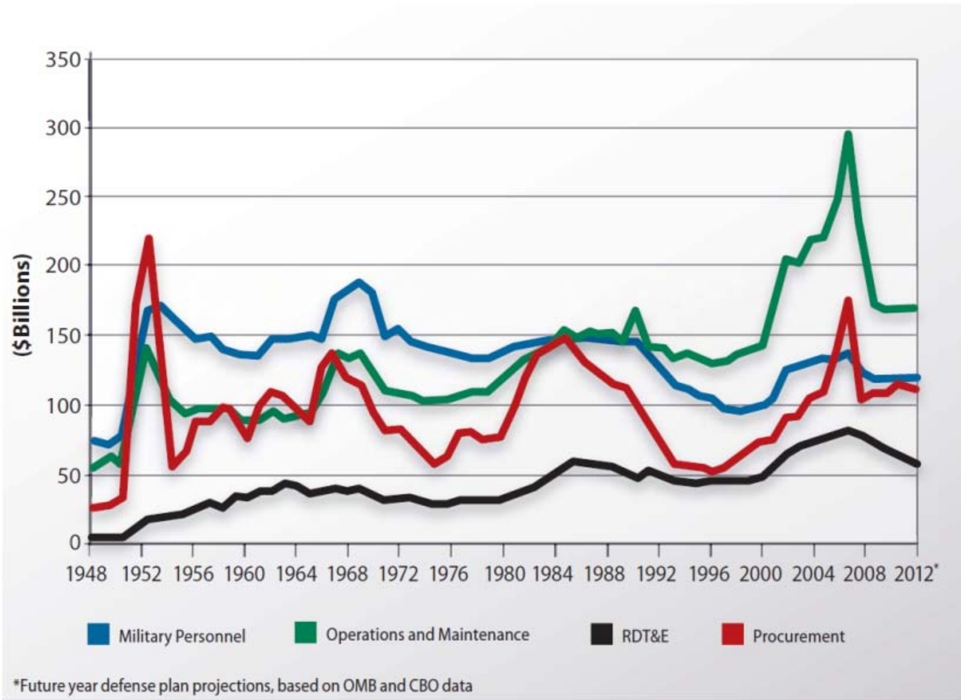


Figure 2: DoD Budget in $FY09 (Bayer, 2009:62)

Figure 3 displays the Air Force's O&M budget authority in constant FY10 dollars, and evidences the decrease in O&M funding forecasted in Figure 2. After increasing more than 26 percent from FY05-F10, the Air Force's annual O&M budget has decreased more than 17 percent ($9.3 billion) in the past two fiscal years; evidence that the appropriation is undoubtedly becoming more constrained. This constrained fiscal environment can debilitate Air Force leaders' abilities to fund critical activities. For this

reason, as previously mentioned, Secretary Gates has urged Service leaders to identify and exploit cost-saving opportunities.

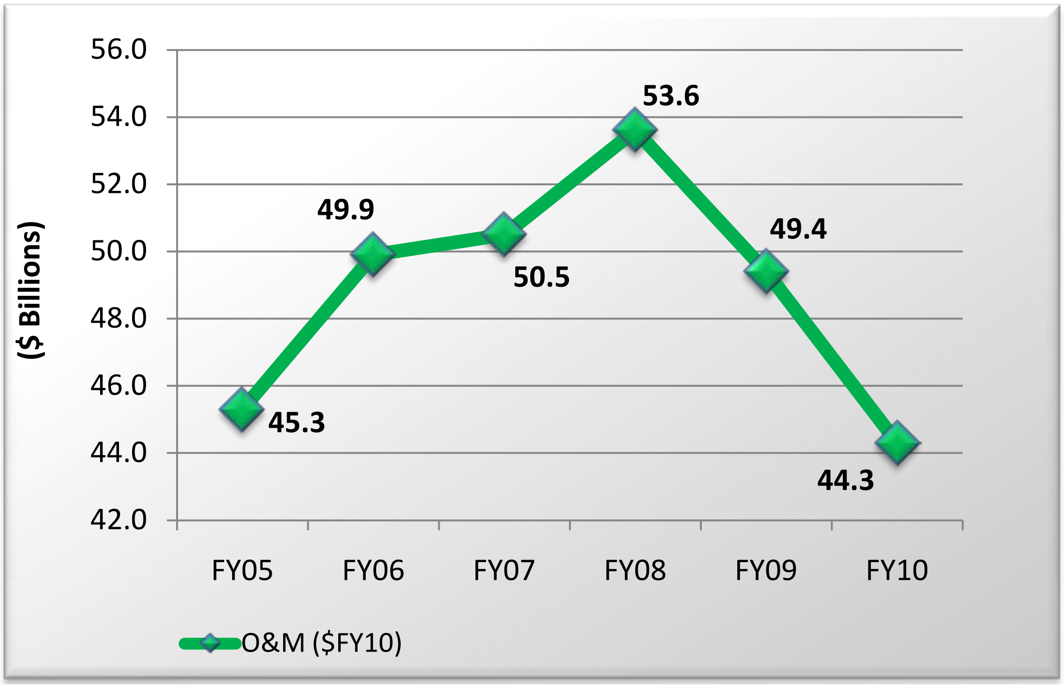


Figure 3: AF O&M Budget in $FY10 (Spencer, 2009: 10)

Targeting O&M Travel

One area of potential interest for cost-savings within the O&M appropriation is travel. In FY09, the Air Force spent$1.37 billion on personnel travel and plans to spend $1.29 billion in FY10 (Department, 2010:14). However, despite its generation of large annual expenses, travel rarely receives attention in discussions on cost-saving strategies. This is simply because the Air Force does not have the ability to influence the market forces that dictate airfare and per diem rates. To date, the Air Force, like its fellow government agencies, has relied heavily on the annual General Services Administration

(GSA) contract, which obtains reduced airfare between select cities for federal employees on official travel, to reduce and stabilize its O&M travel expenses (GSA, 2009).

Although the nature of travel expenses are seemingly inflexible, opportunities to reduce the overall impact of travel on the Air Force's budget do present themselves through an analysis of its facility locations, transportation networks, and the flow of its personnel through such networks. This is simply because locations for one's departure and arrival are influential factors that dictate the cost of travel. For example, some locations may typically require higher airfare costs to travel to and from than others. Similarly, because the average cost-of-living is unique to a specific location, travelers may require significantly higher, or lower, per diem rates depending on their destinations. In addition, the quantity of personnel traveling and the duration of their trips significantly influences the overall cost to the Air Force.

Given this information, it would behoove leaders across the Department of Defense, when deciding where to position facilities or activities, to determine the impact potential locations have on their respective service's O&M travel expenses. Placing activities, such as training, in locations where personnel can travel to and from inexpensively helps minimize travel costs. This, in turn, can make the funding, otherwise spent on travel, available to finance other previously unfunded requirements; a benefit that would mitigate some of the problems caused by current budget constraints.

ECSS Training – An Opportunity for Research

The Air Force logistics community is currently working to develop and implement the Expeditionary Combat Support System (ECSS), a web-based computer

system that will replace hundreds of outdated legacy systems and streamline logistics operations through process integration. The successful implementation of ECSS requires thousands of its globally dispersed future end-users to receive training on how to operate the new system. In response to this training requirement, the Logistics Transformation Office (LTO) is currently researching potential locations where ECSS training can be conducted. Given the Air Force's constrained O&M budget, the question as to where ECSS end-users should receive training provides a great opportunity to determine what impact training facility locations can have on O&M travel budget.

Purpose of This Study

In this study, we evaluate the potential training locations for the Air Force's Expeditionary Combat Support System with respect to their impact on O&M travel costs. By establishing the training location(s) that reduce travel expenses, we aim to provide more flexibility to the Air Force's constrained fiscal position. Furthermore, by determining the cost minimizing location(s), we hope to not only minimize travel expenses within the ECSS training transportation network, but also provide evidence that the application of our approach can reduce travel expenses in other contexts within the Department of Defense. The questions outlined in the following section guide our research.

Research Questions

1. Given various levels of demand for instructor led training (ILT), and ideal supply capacities at potential ECSS training facilities, which supply location(s) minimize O&M travel costs for the Air Force?
2. What are the supply capacity thresholds at the potential ECSS training facilities that dictate the aforementioned travel cost-minimizing location(s)?

Chapter Summary

In an ever-constraining fiscal environment, leaders within the Department of Defense must seek new ways to stretch available funding to accomplish their mission. Travel expenses account for a substantial portion of the military's budget authority and are a suitable target for cost reductions. In an effort to alleviate some of the pressures associated with limited budgets, we use a linear programming approach, discussed in Chapters II and III, to determine training locations for the Expeditionary Combat Support System that minimize O&M travel costs for the Air Force.

This chapter provided an outline of the purpose for our study and stated the specific research questions addressed in subsequent chapters. In Chapter II, we discuss the driving force behind ECSS, and summarize the implementation plan for training its end users. In addition, we review previous literature pertaining to a relevant linear programming problem, known as the classical transportation problem, as well as an approach to finding its solution. Chapter III details the data, and its sources, used in our study as well as the methods we employ and assumptions we make to answer the research questions. In Chapter IV, we present the results of our research and an analysis of our

findings. Finally, we state our concluding recommendations for ECSS training locations, research limitations and recommendations for future research in Chapter V.

Chapter II: Literature Review

Overview

The purpose of this chapter is to support the research methodology we employ in Chapter III by illustrating how a linear programming approach for the selection of one or more locations for ECSS end-user training can potentially minimize the Air Force's travel expenses. We begin by providing the reader a general overview of ECSS, including its background, purpose, and plan for training implementation. Then, we briefly review the optimization technique, known as linear programming, to demonstrate how problems, similar to the one addressed in this research effort, have been formulated and efficiently solved in the past.

The Need for Transformation

On the day prior to the terrorist attacks that took place on September 11, 2001, then Defense Secretary, Donald H. Rumsfeld spoke of the need for transformation within the Department of Defense. An excerpt from his remarks on that day follows.

> Our challenge is to transform not just the way we deter and defend, but the way we conduct our daily business. Let's make no mistake: The modernization of the Department of Defense is a matter of some urgency. In fact, it could be said that it's a matter of life and death, ultimately, every American's.

Although spoken nearly a decade ago, Secretary Rumsfeld's words hold true more so today than they did in 2001. The manner in which the Air Force conducts operations has changed dramatically over the past two decades. Instead of a large garrison-based force postured for the Cold War, the Air Force, which has reduced significantly in size, now engages in multiple contingencies simultaneously around the globe (Department,

2008:7). Current logistics processes, which date back to World War II, lack the efficiency to guarantee sustainable support required by the Air Force in its current and future operations (ECSS, 2009).

Surprisingly, various metrics indicate that current Air Force business operations actually improved over the past ten years despite the fact logistics processes have not changed, or been modernized. For example, since 1999, maintenance wait time has decreased by nearly 36%, from 14 days to 9 days. Unfortunately, in this instance, the improvement is a byproduct of the Global War on Terrorism, which necessitated large capital infusions from Congress. In the United States' current fiscal environment, constrained government budgets will not permit such improvements to continue in the future, especially when the archaic processes, and outdated information technology (IT) systems used by the Air Force create inefficiencies that dramatically increase the cost of logistics operations. Since 2003, the Air Force has spent over $27.5 billion annually on its logistics systems and processes; a staggering figure that is expected to grow unless IT systems and processes are updated to better align with the needs of today's warfighter (ECSS, 2009).

Expeditionary Logistics for the 21st Century

In response to the need for business process transformation, the Air Force has initiated Expeditionary Logistics for the 21st Century (eLog21); a campaign plan focused on improving logistics operations with the adoption of industry and Air Force best practices. Through the eLog21 campaign, the Air Force hopes to produce the following four effects: an established enterprise view, integrated business processes, optimized

resources, and integrated information technology (IT). An enterprise view enables Air Force leaders in the logistics community to understand the service-wide impact of their decisions. Integrated processes that cut across all logistics activities provide logisticians the visibility necessary to decrease response time and increase operational flexibility. The transformation of individuals' roles and responsibilities to complement new processes and IT systems eliminates non-value added tasks and optimizes their ability to support the warfighter. Similarly, streamlined financial processes optimize monetary resources to increase logistics capabilities. Finally, IT integration creates transparency across all logistics processes that tie the previously mentioned effects together, "end-to-end business processes are enabled, an enterprise view is established, and resources are leveraged to support enterprise goals" (Department, 2008:22).

The Expeditionary Combat Support System (ECSS)

The IT enabler for the eLog21 campaign is an Enterprise Resource Planning (ERP) system, which is a commercial technology solution, typically used by large corporations. An ERP system consolidates functions such as manufacturing, financials and distributions by facilitating, "the seamless flow of information across an organization…and standardizing business processes and tools across the entire enterprise." An ERP implementation aims to increase an organization's efficiency by reducing inventory levels, maintenance cycles and the effort required for financial analysis and reporting. In addition, ERP systems can assist leaders in making timelier and better-informed decisions, and allow organizations to allocate its resources more efficiently (ECSS, 2009).

The Air Force's ERP implementation, known as the Expeditionary Combat Support System (ECSS), is a modified version of the Oracle Corporation's E-Business Suite, a collection of computer applications dedicated to ERP, supply-chain management and procurement (Oracle, 2009). This modified collection of software packages, or the Oracle Product Suite (OPS), comprises the core of the ECSS system and is intended to integrate data from, and replace, over four hundred of the Air Force's legacy IT systems (CSC, 2009:54). Labeled by senior leaders as, "the single biggest change in the history of Air Force Logistics," ECSS is a monumental undertaking that will change the daily activities of more than 250,000 end-users (ECSS, 2009).

Implementation and Training

Due to its logistical complexity and the large number of end-users it demands, the fielding of ECSS is slated to require three separate release events. During each release, end-users that fulfill specific functions will be targeted to receive training in order to transition from their roles within the Air Force's dated logistical business processes to the new processes enabled by ECSS. In other words, individuals whose day-to-day activities will be impacted by the implementation of ECSS will be taught how to accomplish their tasks, which previously required the use of Air Force legacy systems. Release 1 will target end-users that perform base and intermediate level maintenance duties and logistics readiness functions. Release 2 will concentrate on the individuals that manage purchasing and supply chain management, product life cycle management and other support functions. Finally, Release 3 will focus on depot-level maintenance and supply,

as well as any other remaining logistics functions remaining from the previous release events (ECSS, 2009).

The ECSS Program Management Office (PMO) and the Logistics Transformation Office (LTO) have teamed with the Computer Sciences Corporation (CSC) to ensure ECSS end-users are adequately trained for a successful transition from the Air Force's old to new logistics business processes. CSC is currently anticipated to train all of the estimated 250,000 ECSS end-users in the Air Force; however, due to the global dispersion of the trainees, CSC will provide approximately ninety percent of the training via computer-based, web-accessed material. The remaining end-users who do not receive computer-based training (CBT), roughly ten percent of all ECSS trainees, will receive instructor-led training (ILT), whereby CSC instructors interact with training participants in a face-to-face classroom setting (CSC, 2009:20).

Concerns with the Proposed Training Approach

In a 2009 study, researchers found that CSC's current approach to ECSS end-user training, which emphasizes the use of CBT, varies drastically from those used by other large businesses that have successfully implemented ERP systems. In fact, according to the managers interviewed in the study, paper based training is the only training approach that is inferior to, or less preferred than, CBT. The study's respondents argue that CBT is helpful in providing generalized training, but should not be a primary training method, especially for something as important and complex as an ERP system. In their opinion, CBT does not accurately portray the many complexities end-users face during their day-to-day activities within the system. Conversely, the results of the study indicate that ILT

is clearly the preferred approach to training ERP end-users. Each company included in the study used ILT for its primary training because it allows employees to escape daily work distractions, focus on training, ask questions, and learn to work in the actual system as opposed to simply watching a tutorial online (Sprague, 2009).

After sponsoring the aforementioned research paper, the Logistics Transformation Office (LTO), whose responsibility is to gather, “end-user requirements and ultimately [be] the voice of, and the advocate for, the end-user community” (Cain, 2007:36), has expressed its concern for the current ECSS training approach, particularly the decision to use CBT as the primary training medium. The Air Force is familiar with CBT as it uses this approach to accomplish a large majority of the refresher training it requires of its members each year. However, as indicated by the managers in the study mentioned above, CBT works well when learning general concepts and simple processes, but not when learning to use complicated systems that require hands on experience to gain familiarity.

ILT, on the other hand, provides end-users with the interactive training environment that fosters the knowledge transfer required for end-users to understand the intricacies of a complex system. With only ten percent of ECSS end-users scheduled to receive ILT, the Air Force and LTO are concerned that the remaining ninety percent receiving CBT will be inadequately trained to successfully implement what has been dubbed, “the world’s largest, single instance ERP [system]” (Hartman, 2007:24).

An Organic In-House Training Solution

To alleviate the growing concern for adequately trained ECSS end-users, the LTO is investigating potential training locations where Air Force personnel, rather than CSC employees, can provide ILT to ECSS end-users that would otherwise receive CBT. The Combat Readiness Test Centers (CRTCs) and Air Logistics Centers (ALCs) listed below are all being considered as potential training locations because they have facilities in place that can accommodate the simultaneous training of many personnel.

1. Gulfport CRTC, Mississippi
2. Savannah CRTC, Georgia
3. Alpena CRTC, Michigan
4. Volk Field CRTC, Wisconsin
5. Hill ALC, Utah
6. Hanscom ALC, Massachusetts
7. Tinker ALC, Oklahoma
8. Robins ALC, Georgia

Providing organic training at one or more of the above installations would increase the number of end-users who receive ILT without increasing the Air Force's financial obligation to CSC because the training would be facilitated by Air Force personnel. However, despite avoiding the cost of increasing the contractor's ILT responsibilities, organic training, depending on its scope, can carry a heavy price tag, particularly for travel. For example, if the LTO determines that fifty percent of all the estimated 250,000 end-users require ILT then forty percent, or approximately 100,000

personnel, will have to be trained by organic in-house trainers in addition to the 25,000 personnel already receiving ILT from CSC employees. Undoubtedly, a large portion of these 100,000 end-users would require travel and lodging accommodations at a location away from their home station.

As discussed in the previous chapter, personnel travel usurps a large quantity of the Air Force's O&M dollars each year, and providing organic in-house training to ECSS end-users would intensify the strain placed on the Service's already tight budget. To this end, it is in the LTO's best interest to determine, what potential training locations minimize costs to the Air Force, and thus minimize the burden placed on the Service's O&M budget.

Although the question of which training location or locations minimize travel costs is straightforward, the solution to such a problem is not necessarily easy to come by. Thousands of trainees spread across the globe, each of which requires various levels of funding to accommodate their specific travel arrangements, coupled with training facility capacity constraints dramatically increases the complexity of the situation. Fortunately, questions of this nature have inspired past researchers to develop an interdisciplinary field of study, known as *operations research*, which centers on finding the optimal solutions to such problems. We discuss a brief background of the operations research field of study and review some of the literature pertaining to its relevant applications in the following sections.

Applying Operations Research

Organizations have changed dramatically in size and complexity over the past several centuries. Increases in the division of labor, the segmentation of management responsibilities, and technological advancements throughout the years have all contributed to the creation of today's large, multifaceted organizations. These organizations have enjoyed increases in efficiency and innovations that have created countless benefits for the members of the organizations as well as their customers and/or communities. However, in addition to these benefits, the aforementioned growth in size and complexity has created new problems and challenges that many organizations must address to succeed in achieving their goals. For example, oftentimes, "the efficiency of [an] [organization's] parts comes at the expense of the efficiency of its whole" (Champy et al., 1993:8). In other words, as organizations grow and responsibilities are segmented, it is possible that the segmented subcomponents become, "autonomous empires with their own goals and value systems, [and] thereby [lose] sight of how their activities mesh with those of the overall organization" (Hillier et al., 1986:3).

The Department of Defense clearly demonstrates this problem, especially in recent years; as each of the Department's many individual subcomponents vie over scarce monetary resources. In the context of our research, consider the Air Force units (Wings, Squadrons, etc.) that require personnel to receive ILT for ECSS. Naturally, each unit would prefer the training location(s) to be located such that the training's impact on their travel budget would be minimized. However, the location that can accommodate everyone's preference is most likely nonexistent and some units will have to spend more than others for their personnel to travel and receive the required training. In this instance,

it is difficult for the individual units to recognize the value of choosing a training location through compromise and determining what destination might minimize the costs to the overall Air Force because the outcome of such actions may ignore their individual unit's best interest. This competitive nature between organizational subcomponents leads to inefficiencies that are further exacerbated when the organization's resources are significantly constrained. Problems of this nature, in the military, business, and industry alike, "and the need to find a way to resolve them provided the environment for the emergence of operations research" (Hillier et al., 1986).

An often-quoted definition of *operations research* is, "a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control" (Morse et al., 1951:1). Also known as management science or decision science, operations research is interdisciplinary in nature because it applies practices from other academic disciplines to include mathematics, statistics, economics and computer science (Ragsdale, 2007). As the definition states, operations research is a scientific method. It is an organized activity, with a body of techniques focused on finding definite solutions to organizations' operational problems. These techniques serve the executive departments, or leaders, within an organization by providing numerically comparable alternatives to a problem. It is then up to the decision makers within an organization to interpret the alternatives and react accordingly.

The quantitative aspects provided to executives through operations research techniques create a foundation for implementing a solution to a problem but oftentimes is not the only consideration required to make a decision. "Many other aspects can enter: politics, morale, tradition, items often important but impossible to express in numbers"

(Morse et al., 1951:1). Therefore, despite providing valuable insight into potential solutions to complex problems, results found using operations research techniques may only answer questions concerning a mere fraction of the problem's overall context. This is true for our research.

Effectively providing the organic in-house ILT, discussed above, to thousands of ECSS end-users is a complex problem that includes many aspects beyond the scope of this research effort. However, determining the training location that minimizes travel costs is nonetheless a critical element that weighs on the overall decision of where organic ILT should be provided. The challenge in our research then is to determine what operations research approach can be used to best answer the question, and then apply it.

Optimization

Recognizing that our research concentrates on determining what potential ECSS training locations result in the lowest travel expenses to the Air Force, we focus our literature review on the field of operations research know as optimization, or mathematical programming. Optimization identifies, "the optimal, or most efficient, way of using limited resources to achieve the objectives of an individual or [organization]," using mathematical models (Ragsdale, 2007). These models are sets of mathematical relationships that characterize the construct of the problem, which can provide decision makers insight into how resources may be allocated in order to attain objectives such as maximizing profits or minimizing costs.

Mathematical programming provides the capability of answering a wide range of questions across many different situations. Naturally, the mathematical models that

accommodate such a variety of problems fall within a broad spectrum of complexity. For this reason, many techniques exist to solve the numerous types of optimization problems. Fortunately, the framework of the ECSS training problem we are researching fits into a category of network optimization problems that can be solved efficiently using a technique known as linear programming.

Linear Programming

Linear programming is a mathematical programming technique that involves using linear objective functions and linear constraints (inequalities) to formulate and solve optimization problems (Ragsdale, 2007:21). George Dantzig, while serving as the Mathematical Advisor to the US Air Force Comptroller, first proposed the technique in 1947. Since that time, linear programming has been the focus of considerable research and become a standard tool that allows organizations to make optimal decisions regarding the allocation of limited resources among competing activities (Hillier et al., 1986). As Dantzig states, "linear programming can be viewed as part of a great revolutionary development which has given mankind the ability to state general goals and to lay out a path of detailed decisions to take in order to 'best' achieve its goals when faced with practical situations of great complexity" (Dantzig, 2002:42). Although applicable across many situations, in practice, linear programming is most commonly used to solve problems associated with network optimization (Bertsekas, 1991:ix).

Network Modeling and the Transportation Problem

Mathematical programming problems, both physical and conceptual, that can be represented, or modeled, using a network (a collection of nodes and arcs) and indicate a

direction, or flow, through the network are known as network flow problems (Jensen et al., 1980:1). Most often, the fundamental objective of these problems is to determine a solution that minimizes total costs, such as monetary payments, distance traveled, or time elapsed, and are thus referred to as minimum cost flow problems (Ahuja et al., 1993:4). To better illustrate the concept of a minimum cost flow problem, consider the description of a typical application below.

> Think of the nodes [within a network model] as locations (cities, warehouses, or factories) where a certain product is produced or consumed. Think of the arcs [connecting the nodes] as transportation links between the locations, each with transportation cost c_{ij} per unit transported. The problem then is to move the product from the production points to the consumption points at minimum cost while observing the capacity constraints of the transportation links. (Bertsekas, 1998:10)

Due to their many diverse applications, minimum cost flow problems have been studied extensively over the past half century. During this time, a select number of the commonly structured problems have been identified as special cases; one of which is the classical transportation problem, or the Hitchcock-Koopmans Transportation problem, named after F. Hitchcock and T.C. Koopmans for their research contributions throughout the 1940s (Kelly, 1991:3). The classical transportation problem, in terms of modeling, is relatively simplistic, as it consists of only a two-level network, on which only one type of good flows. In other words, the problem can be modeled by simply using two sets of nodes; one set representing the origin, or source locations, and the second representing the destination, or sink locations (these two sets of nodes can also be referred to as supply and demand nodes, respectively). In addition, the transportation problem has only one unit transportation cost associated with each of its network arcs, which pair the source and destination nodes (Brandimarte et al., 2007:72). Conveniently, the simple network

structure of the transportation problem allows seemingly complex problems to be modeled in a concise but understandable manner, as evidenced by the linear programming model below.

Minimize
$$\sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} = z \tag{1}$$

subject to
$$\sum_{i=1}^{n} x_{ij} = a_i, \quad i = 1, \dots, m, \tag{2}$$

$$\sum_{i=1}^{m} x_{ij} = b_j, \quad j = 1, \dots, n, \tag{3}$$

$$x_{ij} \geq 0, \quad i = 1, \dots, m, \qquad j = 1, \dots, n, \tag{4}$$

where
$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j = T, \quad a_i \geq 0, b_j \geq 0 \tag{5}$$

x_{ij} = the quantity of goods moved from origin i to destination j

c_{ij} = the cost of moving a unit amount goods from origin i to destination j

a_i = the supply available at each origin i

b_j = the demand for goods at each destination j

m = total number of origins (sources or supply nodes)

n = total number of destinations (sinks or demand nodes).

The objective function (1) is the summation of the costs incurred over all the arcs within the network, assuming that an arc exists for any source-destination pair. The goal then, is to minimize this function, which equates to the total transportation cost. The supply constraint (2) limits the capacity of outflows from any origin. Likewise, the next constraint (3) ensures that the demand is met at each destination node. The lower bound (4) constrains the quantity of goods within the network to assume only nonnegative values (Brandimarte et al., 2007:73). Finally, for a feasible solution to exist, total supply must equal total demand, and both of these values must be nonnegative (5) (Sharma, 1977:929). Figure 4 below is a network representation of the classical transportation problem.

In the context of our research, the nodes within the network can represent the installations where ECSS ILT is required (demand nodes) and where it is provided (supply nodes), while the arcs between these nodes portray the means by which trainees take to travel from their home station to a training location. The costs associated with each arc within the network then are the cumulative travel costs made up of each trainee's mode of transportation to, and the duration of their stay, at the training destination.

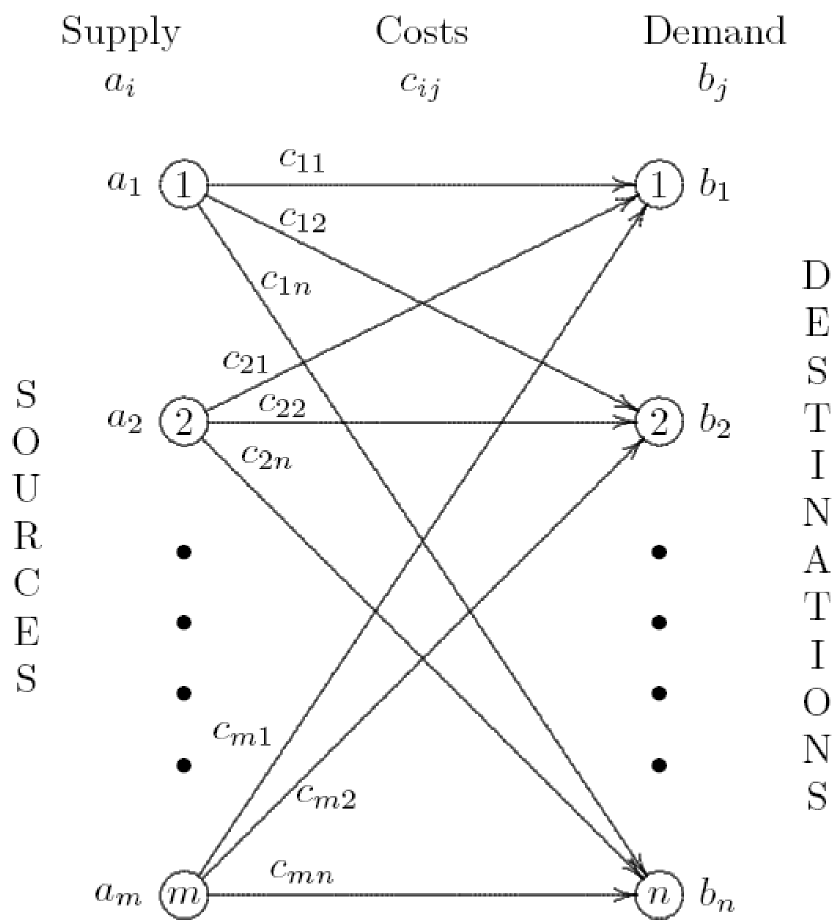


Figure 4: Network Representation of Transportation Problem (Dantzig, 1997:209**)**

Algorithms, Computers, and Software

As mentioned earlier, linear programming provides the ability to find optimal solutions to problems of great complexity. However, this ability is contingent upon not only the accurate formulation of such problems in mathematical terms, as shown above using the transportation problem, but also an efficient means to determine their solutions through the use of algorithms, computers, and software (Dantzig, 2002:42). The complex problems that are typically addressed using a linear programming approach have a high number of possible solutions. For example, consider a seemingly simple problem, where

20 individuals must be assigned to 20 jobs. Assuming the only constraint is to ensure that each person is assigned to exactly one job, the total number of possible solutions is 20!; a number more than 360 million times larger than the world population.

An example as simple as this clearly demonstrates why many decisions regarding complex situations are perhaps made before an optimal solution is determined. Oftentimes it may appear too daunting of a task to sift through and evaluate all possible scenarios to determine the best course of action. This was undoubtedly true prior to the late 1940s, before great strides were made in the development of computers and algorithms that could efficiently solve optimization problems (Dantzig, 2002:42). Today, decision makers enjoy the luxury of having a wide variety of software programs available to execute the steps of proven algorithms on computers with great processing power that can solve virtually any optimization problem. Nowadays, the greatest challenge in solving optimization problems, beyond formulating the problem as a mathematical model, is deciding what algorithm, and thus software, is most appropriate, given the context of the problem.

Since the technique of linear programming was first established in 1947, dozens of effective algorithms have been created for solving mathematical programming problems. Of these, the simplex method, introduced by Dantzig, "is perhaps the most powerful algorithm ever devised for solving constrained optimization problems...because of the pervasiveness of its applications throughout many problem domains, [and] because of its extraordinary efficiency" (Ahuja et al., 1993:402). The simplex algorithm proceeds from one vertex, or extreme point, of the problem's feasible region to another, "in such a way as to continually decrease [increase] the value of the objective function until a

minimum [maximum] is reached" (Luenberger, 1984:30). In other words, the feasible region, which is the set of all possible solutions, is shaped by the problem's linear constraints. The vertices of this region, created by the intersections of the constraint equations are the problem's basic feasible solutions (Todd, 2001:4). The simplex algorithm moves from one basic feasible solution to the next until the optimal solution is found.

To illustrate the simplex method's iterative process, consider a simple linear programming problem with only two variables, X and Y, as depicted in Figure 5 below. The feasible region, in yellow, is bound by the linear constraints, represented by the red, blue and green lines, and the model's lower bounds, indicated by the X and Y axes. The vertices, or the basic feasible solutions, are located at the corners of the feasible region, labeled A, B, C, D and E. The simplex algorithm begins at one of these corner-point solutions, then moves to an adjacent corner-point if it is better (as measured by the objective function).

Although infinitely many solutions exist within the feasible region, only the vertices are analyzed. This is simply because mathematical proofs reveal that if the problem has a bounded feasible region in the direction of improving the objective function (i.e. a finite minimum in the case of minimizing the objective function), "then at least one optimal solution is a basic feasible solution" (Pike, 2001 or Garvin, 1966:21). Therefore, the algorithm ends when the current basic feasible solution is optimal with respect to all other adjacent vertices.

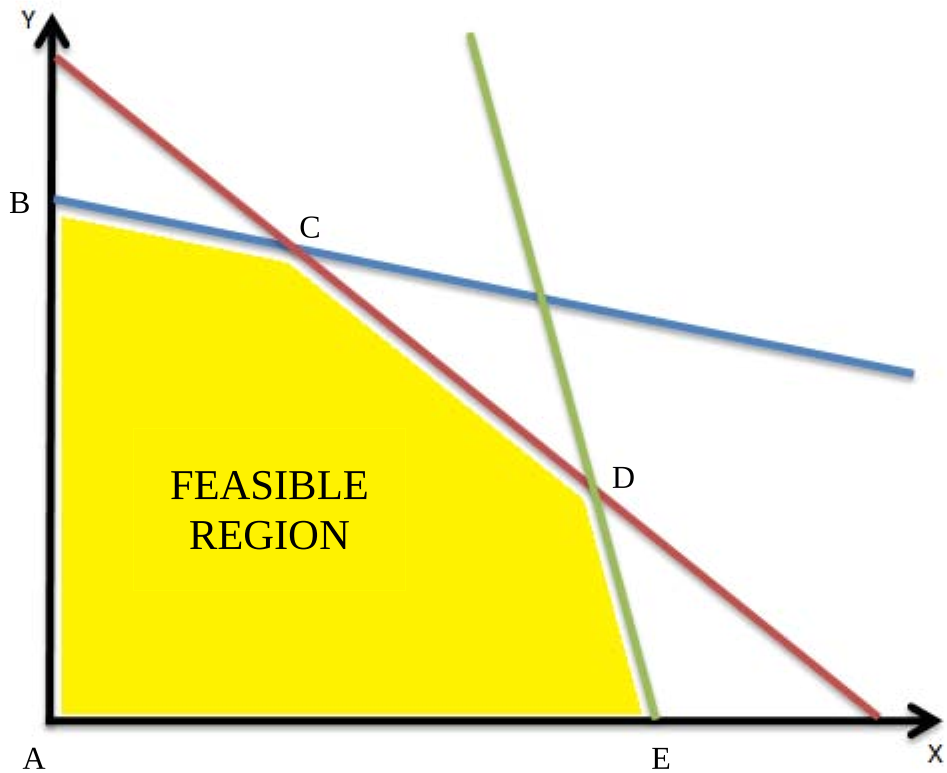


Figure 5. Linear Programming Problem and its basic feasible solutions

The example shown in Figure 5 represents a relatively simple linear programming problem with only two variables and few constraints. Situations of greater complexity, such as the one addressed in our research, require many decision variables and a large number of constraints that create a feasible region, which cannot be simply depicted as a two-dimensional shape. A linear programming problem that requires more than two decision variables, has a feasible region that is polyhedral in shape and the number of basic feasible solutions to be analyzed in search of an optimal solution becomes cumbersome. It is in these complex situations where the efficiency of the simplex method can truly be appreciated.

Shortly after the introduction of the simplex algorithm, adaptations and extensions to the method were made to solve network flow problems more efficiently in the 1940s and 1950s. However, despite these advancements, the simplex method was not always seen as the most efficient linear programming algorithm. During the 1950s and 1960s, it was generally accepted that primal-dual algorithms were superior to the simplex method in terms of solving network flow problems. Then, in the 1970s, research contributions focused on the implementation of the simplex method reduced the problems the algorithm encountered in practice, such as cycling, where the algorithm would continue forever without converging to an optimal solution **(**Dantzig, 1997:149**)**. "These contributions established the superiority of the network simplex method and led to its acceptance as the most efficient for solving minimum linear cost network flow problems" (Florian et al., 1996:266).

Numerous methods, including new primal-dual algorithms have since been created, which rival the efficiency of the simplex method. However, in practice, the simplex algorithm remains the dominant choice for solving linear programming problems. This is evidenced by its wide application in the many optimization software packages available today; particularly Microsoft® Excel Solver, "the most widely distributed and almost surely the most widely used general-purpose optimization modeling system" (Fylstra et al., 1998:29).

Chapter Summary

In this chapter, we discussed the driving force behind the Air Force logistics' improvement campaign plan, elog21, and its technological enabler, ECSS. We explained

how the rapid and dramatic changes in military operations over the past two decades have left the manner in which the Air Force conducts its daily business outdated and how, in an effort to alleviate the high costs and inefficiencies created by its dated processes, the Service's logistics community has responded.

We continued with a discussion about the inherent difficulty associated with successfully implementing a system as complex and far-reaching as ECSS. Specifically, we stated that adequate training must be provided to the system's thousands of globally dispersed end-users, but that doing so is expensive. We then reiterated that in the Department of Defense's currently constrained fiscal environment, it is prudent to determine a training location that minimizes costs to the Air Force.

Next, we provided the reader a look into our thought process as we sought-after an appropriate methodology to accomplish our research objective. Among the many techniques within the interdisciplinary field of operations research, we found that linear programming proves to be a suitable approach for determining a travel cost minimizing ECSS training location. Furthermore, the structure of the classical transportation problem and the Microsoft® Excel Solver software's execution of the simplex algorithm provide the blueprint and means, respectively, to move ahead with the data collection and methodology for our research, explained in the following chapter.

Chapter III: Data Collection and Methodology

Overview

In this chapter, we describe the data used in our analysis and the methodology we employ to answer the research questions posed in Chapter I. First, we restate the problem and explain the decision variables, coefficients, constraints, and objective function used to create a suitable linear programming model for solving the problem. In addition, we discuss where the data for these variables were acquired, and the assumptions used to create the model's mathematical relationships. Finally, we detail how we used optimization software to determine the results discussed in Chapter IV.

Restatement of the Problem

As mentioned earlier, in the Department of Defense's constrained fiscal environment, military service leaders must seek opportunities to reduce spending while continuing to meet operational requirements. One such requirement demands thousands of globally dispersed end-users to receive training in order to operate the Air Force logistics' new enterprise resource planning system, ECSS. The problem we seek to resolve with this research effort is to determine which of the potential training locations will minimize the combined travel costs for the ECSS end-users, and thus reduce the training requirement's impact on the Air Force's O&M budget. After reviewing the literature for possible research methods, we found that linear programming is an appropriate approach for finding a solution to the aforementioned problem, given its context.

The Linear Programming Model

To formulate the problem addressed in our research as a linear programming model, or more specifically as a classical transportation problem, we first identify the appropriate decision variables and objective function coefficients for the potential ECSS training transportation network. Then we state the objective function and constraints as linear combinations of the decision variables. Finally, we identify the lower bounds of the decision variables to ensure the model has a bounded feasible region in the direction of our objective function.

Decision Variables

In the context of our research problem, the decision variables, x_{ij}, represent the number of ECSS trainees to travel from their home station i to a certain training location j, and are ultimately what we are attempting to find the optimal values for. As mentioned in Chapter II, the logistical complexity of implementing ECSS demands three separate release events. Currently, the contract with CSC only covers Release 1, during which over 40,000 end-users located among 186 installations around the globe are scheduled to be trained. The ILT portion of Release 1 will be divided into a pilot/initial operational test and evaluation (IOT&E) phase and eight subsequent phases, totaling nine training phases. Thus, each of the 186 installations referred to above will have its ECSS personnel receive training during one of the nine training phases in Release 1.

To illustrate how we define the decision variables in our linear programming model, consider the pilot/ IOT&E training phase, during which the following six installations will have ECSS end-users receive ILT: Hanscom Air Force Base, MacDill

Air Force Base, Muniz Air National Guard Base, Ellsworth Air Force Base, Colonel Bud Day Field, and Joe Foss Field. Each of these installations are designated a number 1 through 6, respectively. Now consider the eight potential training locations listed in Chapter II and designated the numbers 1 through 8, respectively. In the network representation of our model below, the six installations that require training are represented as demand nodes *i* and the potential training locations are represented as supply nodes *j*. The decision variables then, are the number of individuals traveling on the arcs that connect the demand and supply nodes. For example, $x_{11,}$ is equal to the number of trainees traveling from the first demand location, Hanscom AFB, to the first supply location, Gulfport CRTC. Similarly, x_{28}, represents the number of trainees traveling from the second demand location, MacDill AFB, to the eighth supply location, Robins ALC.

The pilot/IOT&E training phase is the smallest, in scope, of all the phases in Release 1. The six installations that require training multiplied by the eight possible training locations creates a linear programming model with forty-eight decision variables. Phase 7 of the training in Release 1 considers the training demands of twenty-six installations, and thus creates the largest of our models with over two hundred decision variables.

The information regarding the demand locations targeted to receive ILT for all of the phases within Release 1 were provided by the LTO and are current as of December, 2009. These locations are not likely to change; however, it is possible that some locations will switch between phases by the time the training is actually implemented in 2012. For the purpose of this research effort, we assume that the locations currently

considered for receiving and providing training will not change. Appendix A contains tables that indicate which demand locations are currently scheduled to receive ILT within each of the nine training phases.

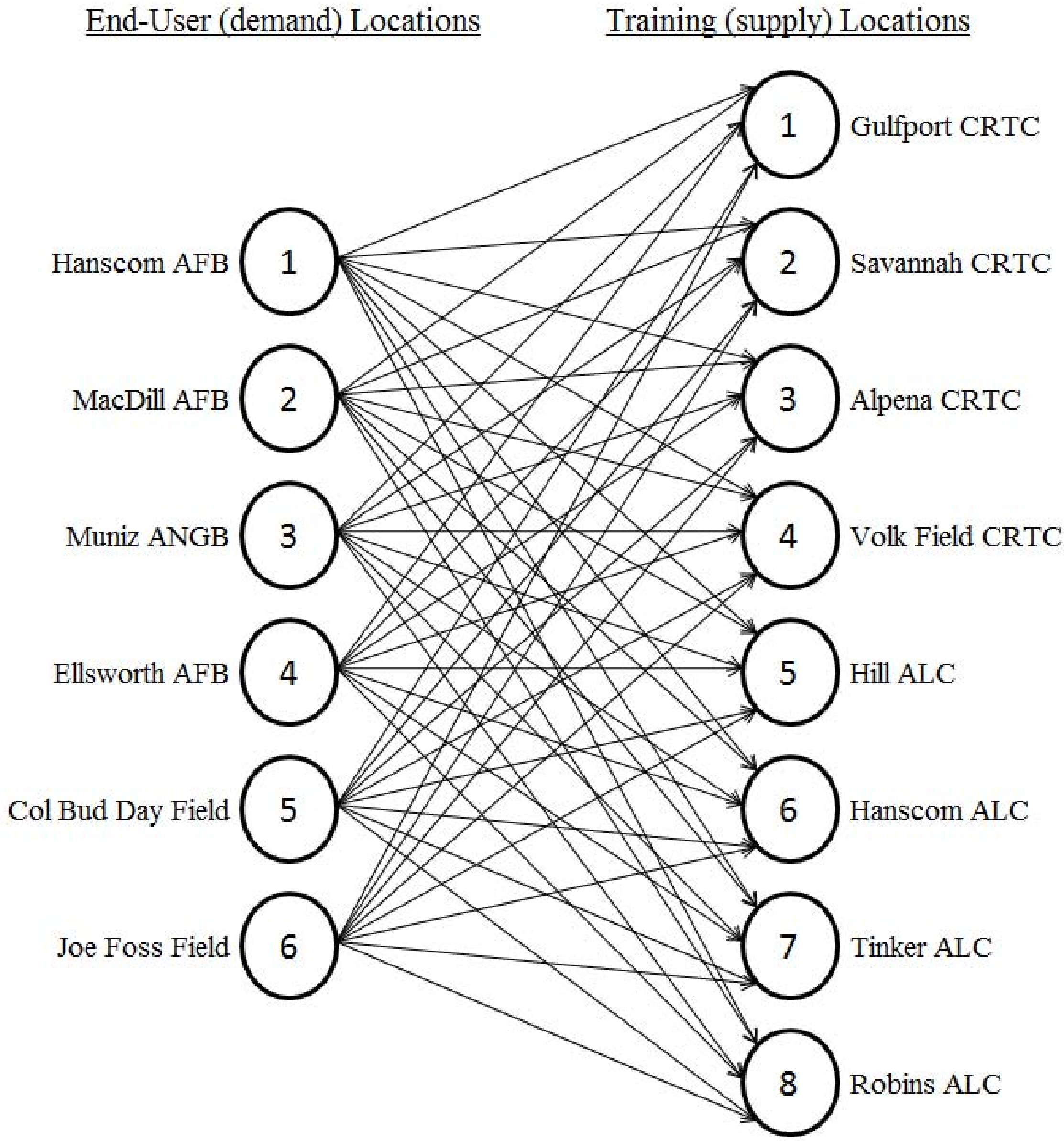


Figure 6. Network Representation of Pilot/IOT&E Training Phase

Objective Function Coefficients

To calculate the value of the objective function coefficients in our research problem, c_{ij}, we summed the monetary travel costs required for ECSS trainees to travel roundtrip from their home station *i* to a certain training location *j*. The travel costs we accounted for include transportation expenses (i.e. airfare, personal vehicle mileage reimbursement, airport shuttle fare), and per diem. With respect to the pilot/IOT&E training phase discussed above, and its network representation shown in Figure 6, the coefficients represent the costs associated with moving one person along the arcs that connect the demand node and supply nodes.

As an example, consider $c_{16,}$ which equals the cost of sending one trainee from the first demand location, Hanscom AFB, to the sixth supply location, Hanscom ALC. In this instance, the trainee's home station is collocated with the training facility, and thus c_{16} is equal to $0 because there are no transportation costs. Similarly, c_{68}, which is the cost of sending one trainee from the sixth demand location, Joe Foss Field, to the eighth supply location, Robins ALC, is equal to an estimated $997. This is calculated by summing the cost of roundtrip airfare from Sioux Falls, South Dakota to Atlanta, Georgia ($402.00); the cost of a roundtrip airport shuttle from the Hartsfield Airport in Atlanta to Robins AFB ($62); and per diem for two travel days and four training days ($533).

To estimate the cost of airfare for the coefficients in our model, we assume that each potential ECSS trainee is a Department of Defense employee and when air travel is necessary, the trainees fly using only government-contracted flights. Each fiscal year, the General Services Administration (GSA) signs one-year contracts with commercial air carriers to establish fixed airfare prices for federal employees traveling between pairs of

select cities. These government-contracted flights are known collectively as the GSA City Pair Program and cover more than five thousand city pairs (GSA, 2009). Assuming that ECSS trainees use only flights from the City Pair Program allows us to ignore the volatile impact market forces have on typical commercial airfares.

We also assume that all potential ECSS trainee's use the Defense Travel System (DTS) to arrange their duty related travel accommodations. DTS is a web-based system that allows Department of Defense employees to personally plan and select the travel means that best suit the requirements for their temporary duty assignments. More importantly to our research, DTS provides measures to ensure travelers remain compliant with Federal Travel Regulation 301-10.106, which states that federal employees, "must always use a contract city pair fare for scheduled air passenger transportation service," unless one of the limited exceptions exist. Furthermore, DTS not only displays flights included in the City Pair Program, but will also combine multiple contracted city pair flights to create connections between cities that are not paired under contract (DTMO, 2009:2-51).

For example, Louisville, Kentucky and Oklahoma City, Oklahoma are not contractually paired, but both of these cities are paired with Chicago, Illinois. In this instance, DTS can pair Louisville and Oklahoma City via Chicago. When necessary, we incorporate this same logic into the construction of our model by using the cheapest connections available to pair cities that are not already connected under the City Pair Program. In our model, ECSS trainees traveling from Standiford Field to the Tinker ALC fly from Louisville to Chicago ($105), from Chicago to Oklahoma City ($125), and then return on the same route for a roundtrip total of $452.

We obtained the City Pair Program airfares used in our model from the GSA website. Each year, GSA posts spreadsheets containing the current fiscal year's city pairs and their associated airfare. Historical city pairs and airfares from previous fiscal years are also available, but for our research, we use the most current, FY 2010, data.

In our model, we assume that each potential ECSS trainee will be allowed one travel day to arrive at any of the potential training locations, as most travelers will travel via airplane within the continental United States. However, a significant portion of the demand locations in our problem are located within 400 miles of a potential training location; the distance for which one travel day is allowed for ordered travel (PDTATAC, 2009: U3A-2). Individuals at these demand locations are faced with a choice between flying and driving a personally owned automobile (POA) to their potential training destination. Personal preference will dictate which conveyance is used in most cases, but for our model, we assume that all trainees, whose home station is located within 250 miles (approximately a 4.5 hour drive) of a training location, will opt to drive rather than fly, unless doing so is monetarily disadvantageous to the government.

To determine the mileage reimbursement for the individuals we assume will drive to their training destination, we multiply the estimated miles traveled by the 2010 mileage rate of $0.50 per mile. To estimate the miles traveled between the demand and supply destinations, we reference the Defense Table of Official Distances (DTOD); "the official source for worldwide distance information used by the Department of Defense" (SDDC, 2009). For example, according to the DTOD, the Savannah/Garden City ANG located in Garden City, Georgia is 162 miles away from Robins ALC. Using the $0.50 per mile

rate mentioned above, the cost of a sending a Savannah/Garden City ANG trainee on the 324 mile roundtrip to Robins ALC is $162.

In our model, similar calculations are made for those individuals who must travel more than 40 miles roundtrip to the nearest available airport. For example, ECSS end-users at Beale AFB must travel 61 miles to the airport in Sacramento, California in order to travel to any of the potential training locations. In this instance, $61 is added to the individuals total travel cost. Oftentimes airport shuttle services are available, and less expensive than traveling by POV. In these instances, we add the appropriate shuttle fare to the total travel cost. For shuttle fare prices, we referenced the Air Force installation websites for recommended sources of travel, and chose the least expensive shuttle available. For example, the $62 shuttle fare noted above from Hartsfield Airport to Robins ALC is provided by Groome Transportation in Atlanta.

The final cost element that is incorporated into the calculation of our model's objective function coefficients is per diem. Currently, the ratio of military to civilian ECSS end-users at each demand location is unknown. Therefore, the number of trainees expected to obtain lodging and meals on the training installations cannot be accurately estimated. As such, we assume that each traveler will require full per diem for lodging, meals and incidentals. We also assume that all end-users will require one travel day to and from their training location, CONUS travelers will require four days of training, and OCONUS trainees will require five days of training.

Our assumptions for the training duration stem from the estimates provided by CSC in the ECSS End Users Training Plan (CSC, 2009:8). In this document, three types of end-users are identified: super users, regular users, and casual users. Super users

represent 20% of all end users and are expected to require 10 days of training while regular and casual users each represent 40% of all end users and are expected to require 3 days and 1 day of training, respectively. Given this information, the average expected duration for all ECSS end-users is 3.6 days, which we round conservatively to 4 days. We then assume an additional training day for end-users traveling from outside the continental United States to account for the fact that these travelers typically arrive for training a day early to help adjust to the change in time zone.

We obtained the FY2010 per diem and mileage rates used in our model from the Department of Defense's Per Diem, Travel and Transportation Allowance Committee (PDTATAC) website, www.defensetravel.dod.mil. The final values for each objective function coefficient used in our study are presented in Appendix A.

The Objective Function

The objective function of our linear programming model seeks to minimize the total network's travel costs created by the products of the decision variables and coefficients discussed above. As an example, below is the objective function for the pilot/IOT&E training phase for Release 1, which accounts for the six demand locations and eight supply locations previously discussed.

Minimize $$\sum_{i=1}^{6}\sum_{j=1}^{8} c_{ij}x_{ij} = z \qquad (6)$$

Linear Constraints and Lower Bounds

The linear constraints used in our model ensure the demand for ECSS training at each requiring installation is met without exceeding the training capacity at any of the potential training locations. As mentioned in Chapter II, CSC is contracted to provide ILT to 10% of all ECSS end-users; leaving the remaining 90% of end-users available to receive ILT from Air Force personnel. However, of the remaining 90% of end-users, the number that will actually receive in-house training is yet to be determined. Given this uncertainty, we replicate our model multiple times, assuming different levels of demand for each replication.

For example, in the first replication, we assume 10% of all end-users will receive organic ILT; in the second replication, we assume 20% of all end-users will receive organic ILT, and so on. In addition, we assume that the percentage used in a replication applies to each installation. In other words, if we assume 10% of all end-users will receive organic training, then 10% (rounded up to the nearest integer) of the users at each installation will receive organic training. To illustrate this point, Table 1 below indicates the total number of end-users for the pilot/IOT&E phase, and the number that will receive in-house ILT, provided our model's demand constraint ensures 10% will be trained.

Table 1. Pilot/IOT&E Phase Total End-Users and 10% ILT Demand

DEMAND LOCATION	TOTAL END-USERS	10% ILT DEMAND
Hanscom AFB	71	8
MacDill AFB	294	30
Muniz ANGB	72	8
Ellsworth AFB	345	35
Col Bud Day Field	75	8
Joe Foss Field	69	7
TOTAL	**855**	**86**

We obtained the total training demand (number of total end-users) for each installation, in all phases of Release 1, from the Draft Fielding Sequence, version 6.1, provided by CSC. These values are listed within the tables found in Appendix B.

Like the demand for training in our research problem, the supply capacities at each potential training location are not yet established, but can be modeled using multiple replications. In other words, the total number of traditional classroom seats (i.e. desk/table space for each student) is known for each location, but the number that will be available and/or functional for ECSS specific training is not yet determined. Thus, we approach the supply capacity constraint of our model in the same manner as we do the demand constraint; in the first model replication, we assume each training location can dedicate 10% of its training capacity to ECSS, in the next replication we assume each training location can dedicate 20% of its training capacity to ECSS, and so on.

The LTO conducted site surveys to determine how well the potential training locations suit the needs of an adequate ECSS training environment. The information collected during these surveys is what was used to estimate the training location capacities in our model. Each installation has auditorium and classroom seating available for students. However, in our model we assume that only classroom capacity is relevant because the ECSS End Users Training Plan indicates that typical ILT students will require their own workstation (CSC, 2009:31). In addition, we assume that one class will be taught each week during the seven-week durations of the Release 1 training phases.

Table 2 below indicates the number of seats present at each potential training location, and the seven-week capacity, given a seat availability of 10%. The values in the seven-week capacity column of Table 2 are calculated by multiplying the installation's

total seats (i.e. 327) by the installation's seat availability (10%), rounding this product down to the nearest integer (32), and then multiplying this value by seven to account for one class per week of the training phase (224).

Table 2. Potential Training Location Capacities

SUPPLY LOCATION	TOTAL STUDENT SEATS	7 WEEK 10% CAPACITY
Gulfport CRTC	327	224
Savannah CRTC	266	182
Alpena CRTC	493	343
Volk Field CRTC	136	91
Hill ALC	210	147
Hanscom ALC	414	287
Tinker ALC	620	434
Robins ALC	1332	931
TOTAL	**3,798**	**2,639**

For both the demand and supply constraints in our model, we round the estimated values to integers to create a conceptually accurate and parsimonious model. The decision variables, x_{ij}, in our model represent people, and therefore must be integers (i.e. we cannot send 0.5 persons to receive training). Conveniently, if the demand and supply quantities in a network flow problem have integer values and the problem is solved using the simplex method discussed in Chapter II, the optimal solution will always have integer values (Ragsdale, 2007:235). Thus, by rounding the estimated demand and supply quantities to integers, and using the software discussed later in this chapter, we eliminate the need for an additional constraint requiring the decision variables to be integers.

The final constraint in our model sets a lower bound on the feasible region of the problem by limiting our decision variables to nonnegative values (x_{ij} must be equal or

greater than zero). Our model requires this constraint simply because it is not possible to send a negative number of people from one location to another.

Creating and Solving the Model with Microsoft® Excel Solver

Other than being a globally popular choice for solving optimization problems, we use Microsoft® Excel Solver to construct our model and answer our research questions primarily for two reasons. First, this software uses the simplex algorithm to solve linear programming problems, which is advantageous because coupled with the context of our problem, allows us to obtain integer solutions without employing integer constraints. Second, Microsoft® Excel Solver is not only user friendly, but also very accessible, and it is likely that anyone who is interested in replicating or expanding on our research will have access to a computer with this software.

To construct our model in Excel, we start by creating two tables; the first contains the problem's objective function coefficients (c_{ij}), and the second reflects the problem's decision variables (x_{ij}), demand constraints, and capacity constraints. Next, we establish the objective function by using the software's sumproduct function, which multiplies corresponding components in multiple arrays, like the aforementioned tables, and returns the sum of those products (Microsoft, 2010). Figure 7 below illustrates the initial problem setup for the pilot/IOT&E phase.

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
Hanscom AFB	1578	1008	1645	1369	1333	0	1065	863
MacDill AFB	1458	1466	1423	1181	895	1209	1015	829
Luis Munoz	1841	1662	2017	1395	1657	1567	1759	1759
Ellsworth AFB	2032	2040	1621	1715	1135	1661	2113	1403
Col Bud Day Field	1474	1732	1983	1331	1873	1553	1947	1095
Joe Foss Field	1376	1634	1885	1233	1775	1455	1849	997

Demand Location	Supply Location								Trainees Sent	Trainees Available
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins		
Hanscom AFB	0	0	0	0	0	0	0	0	0	64
MacDill AFB	0	0	0	0	0	0	0	0	0	265
Luis Munoz	0	0	0	0	0	0	0	0	0	65
Ellsworth AFB	0	0	0	0	0	0	0	0	0	311
Col Bud Day Field	0	0	0	0	0	0	0	0	0	68
Joe Foss Field	0	0	0	0	0	0	0	0	0	63
Trainees Received	0	0	0	0	0	0	0	0	Minimum Total Cost	
Training Capacity	2058	1673	3101	854	1323	2604	3906	8386	$0	

Figure 7. Initial Problem Setup in Excel for the Pilot/IOT&E Phase

To clarify, the top table in Figure 7 indicates the monetary cost to travel roundtrip from the demand locations to the supply locations. The bottom table consists primarily of changeable cells (currently populated with 0), that the Solver software will change when it uses the simplex algorithm to find the values for these cells that minimizes the objective function (cell K20) while satisfying the problem's constraints.

The bottom table values in columns K and L are used in conjunction to formulate the problem's demand constraint. The values listed under "Trainees Available," in cells L13-L18, represent the 10% level of demand for ILT, discussed earlier in this chapter. The adjacent cells in column K, under "Trainees Sent," indicate the number of ECSS end-users that are sent from each demand location to a supply location. For example, cell K13 represents the number of end-users sent from Hanscom AFB to receive training and is equal to the sum of cells C13-J13.

The cells used for our model's supply constraints are created and used in the same manner. The values listed in row 20 are the 10% capacity levels for each supply location, as noted earlier in Table 2. Just above these values, in row 19 are the end-users trained, or received, at each supply location. For example, cell C19 represents the number of end-users trained at Gulfport CRTC and is equal to the sum of cells C13-C18.

After creating the initial framework of the problem in Excel, we identify the objective function, decision variables, and constraints in Solver. Figure 8 below shows how these problem elements and parameters are entered to determine the cost minimizing solution for the pilot/IOT&E training phase.

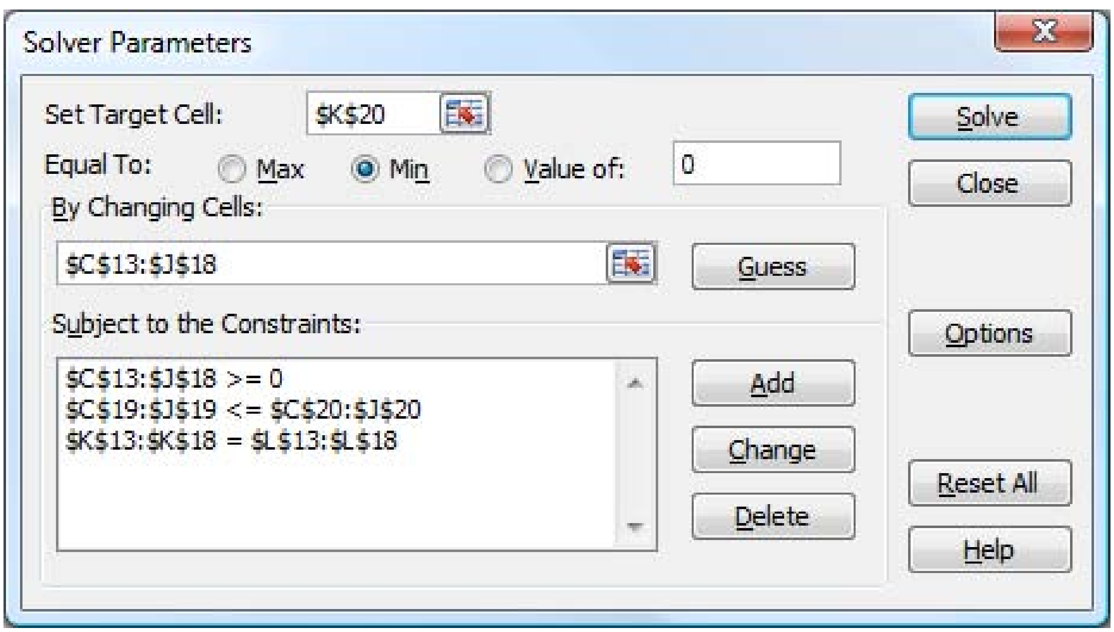
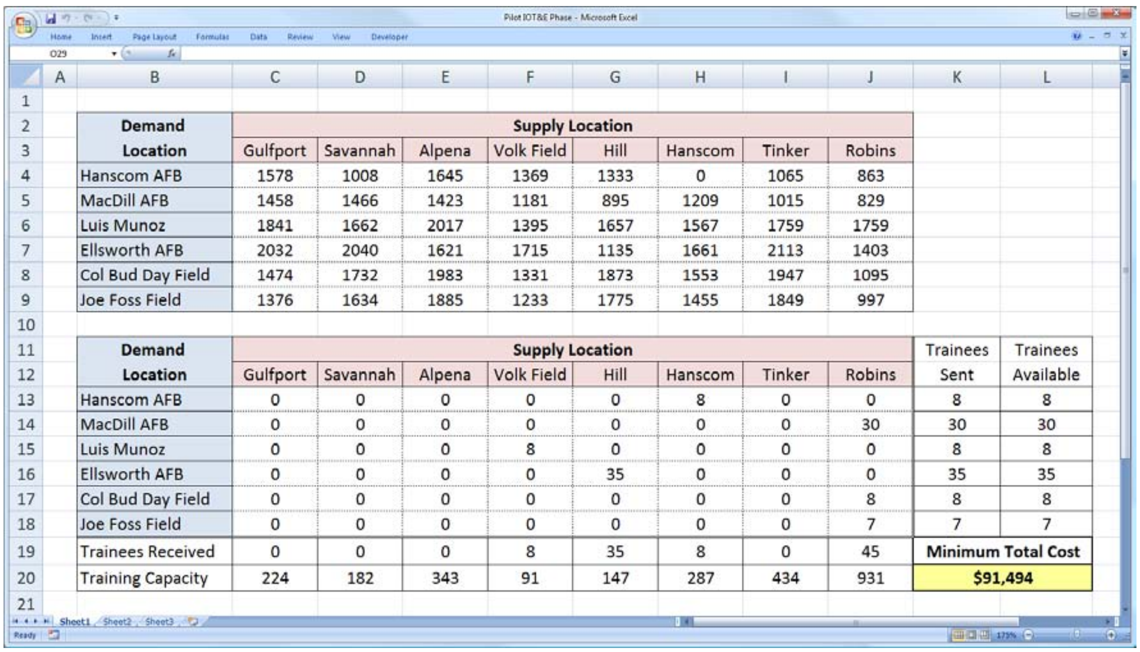


Figure 8. Parameters to Determine the Optimal Solution for the Pilot/IOT&E Phase

The objective function (cell K20) is set as the target cell, and our goal is to minimize this cell. Next, the decision variables (cells C13-J18) are listed as the changing cells. The demand constraint is recognized by setting the "Trainees Sent" in cells K13-

K18 equal the "Trainees Available" in cells L13-L18 and the supply constraint is acknowledged by setting the "Trainees Received" in cells C19-J19 to be less than or equal to the "Training Capacity" in cells C20-J20. Finally, the lower bound of our model is established by stating that the decision variables (cells C13-J18) must assume values greater than or equal to zero. Figure 9 below shows the optimal solution for the pilot/IOT&E phase computed by the optimization software.



Demand	Supply Location							
Location	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
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Joe Foss Field	1376	1634	1885	1233	1775	1455	1849	997

Demand	Supply Location								Trainees	Trainees
Location	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins	Sent	Available
Hanscom AFB	0	0	0	0	0	8	0	0	8	8
MacDill AFB	0	0	0	0	0	0	0	30	30	30
Luis Munoz	0	0	0	8	0	0	0	0	8	8
Ellsworth AFB	0	0	0	0	35	0	0	0	35	35
Col Bud Day Field	0	0	0	0	0	0	0	8	8	8
Joe Foss Field	0	0	0	0	0	0	0	7	7	7
Trainees Received	0	0	0	8	35	8	0	45	Minimum Total Cost	
Training Capacity	224	182	343	91	147	287	434	931	$91,494	

Figure 9. Output for the Pilot/IOT&E Phase's Optimal Solution

From the model output, we can see that all constraints are satisfied. 100% of the trainees available received training, none of the supply locations received a number of students that exceeded their classroom capacity, and none of the decision variables is less than zero. In addition, we can see that reaching the minimum travel cost of $91,494, requires training to be provided at four locations. In this instance, Volk Field CRTC would train 8 end-users from Luiz Munoz ANG, Hanscom ALC would train 8 of its own

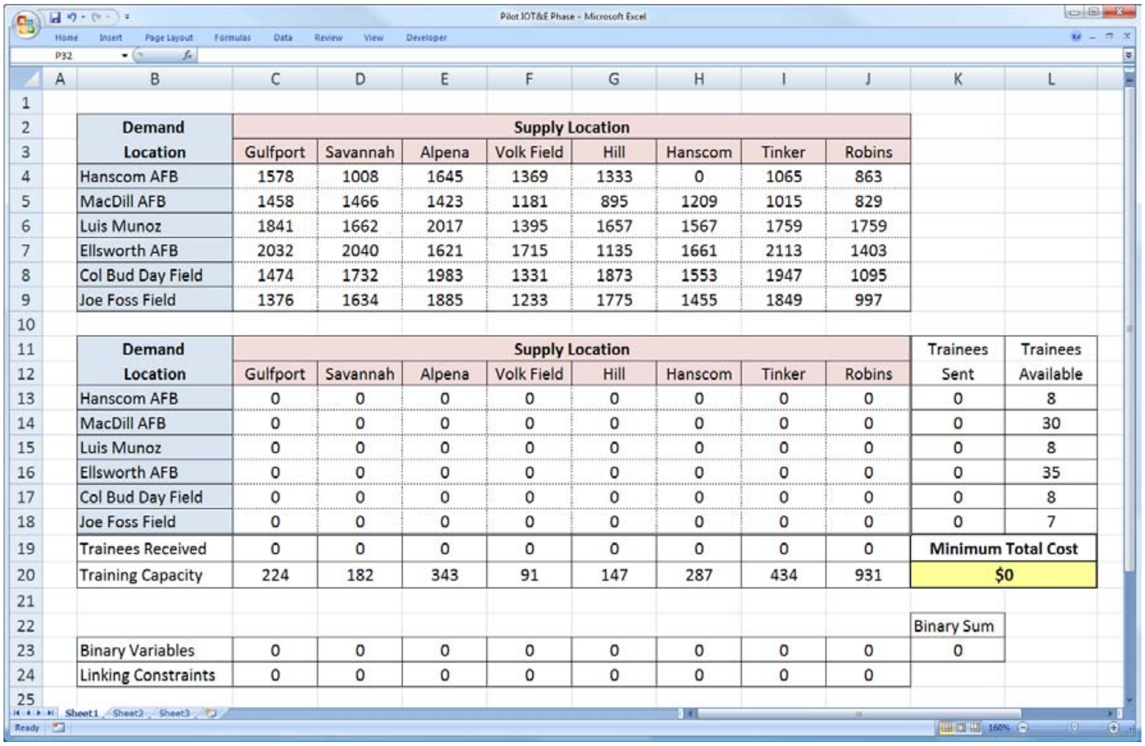
end-users, Hill ALC would train 35 end-users from Ellsworth AFB, and Robins ALC would train 8, 30, 8, and 7 end-users from Hanscom AFB, MacDill AFB, Col Bud Day Field, and Joe Foss Field, respectively.

This information can aid those deciding where to provide training but only applies to a situation where the training demand and capacity are both 10%. In addition, it might not be cost effective to set up training locations to train only eight individuals. For this reason, we not only replicate our model with changes in training demands and capacities, but also change the number of possible locations. We accomplish this by creating an additional side constraint in Solver that limits the number of supply locations selected by the model. For example, the LTO may determine that a maximum of two locations will provide organic ILT in the Pilot/IOT&E phase due to the additional costs required to prepare a classroom for ECSS training (i.e. computer and internet connection at each student workstation). In this instance, we limit the number of supply locations to two, while maintaining the same demand and capacity constraints.

To limit the model to a specified number of supply locations, we use the following constraint, where *D* is the number of supply locations to be used and *y* is a binary variable.

$$\sum_{i=1}^{m} y_i \leq D, \quad y_i = 1, \text{if } x_{ij} > 0, \qquad y_i = 0, \text{if } x_{ij} = 0$$

As a binary variable, *y* equals 1 if a supply location *i* is used, and 0 if supply location *i* is not used. We then limit the sum of the binary variables to be equal or less than *D*. Figure 10 below illustrates how the binary variables are used in Excel to formulate the model constraint.



Demand Location	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
Hanscom AFB	1578	1008	1645	1369	1333	0	1065	863
MacDill AFB	1458	1466	1423	1181	895	1209	1015	829
Luis Munoz	1841	1662	2017	1395	1657	1567	1759	1759
Ellsworth AFB	2032	2040	1621	1715	1135	1661	2113	1403
Col Bud Day Field	1474	1732	1983	1331	1873	1553	1947	1095
Joe Foss Field	1376	1634	1885	1233	1775	1455	1849	997

Demand Location	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins	Trainees Sent	Trainees Available
Hanscom AFB	0	0	0	0	0	0	0	0	0	8
MacDill AFB	0	0	0	0	0	0	0	0	0	30
Luis Munoz	0	0	0	0	0	0	0	0	0	8
Ellsworth AFB	0	0	0	0	0	0	0	0	0	35
Col Bud Day Field	0	0	0	0	0	0	0	0	0	8
Joe Foss Field	0	0	0	0	0	0	0	0	0	7
Trainees Received	0	0	0	0	0	0	0	0	Minimum Total Cost	
Training Capacity	224	182	343	91	147	287	434	931	$0	
									Binary Sum	
Binary Variables	0	0	0	0	0	0	0	0	0	
Linking Constraints	0	0	0	0	0	0	0	0		

Figure 10. Problem Setup in Excel with Training Location Quantity Constraint

The "Linking Constraints" in row 24 simply creates a relationship, or link, between the binary variables and the decision variables, to ensure the binary variables assume the proper values (0 or 1) when a training location is used. For example, cell C24=C19-(SUM(L13:L18)*C23). This relationship, when limited to a value equal or less than zero, ensures that if Gulfport is used as a training location, cell C23 will assume the value of 1, but if Gulfport is not used as a training location, the value of cell C23 will remain 0. It is also important to note, the summation of cells L13-L18 used to create the linking constraints is a substitute for an arbitrarily large number. In this instance, any large number that adequately represents the upper bound on the optimal value of x_{ij} could be used (i.e. 10,000) to obtain the same results. Figure 11 below shows how the linking constraints and binary variables are set up as parameters using the Solver software.

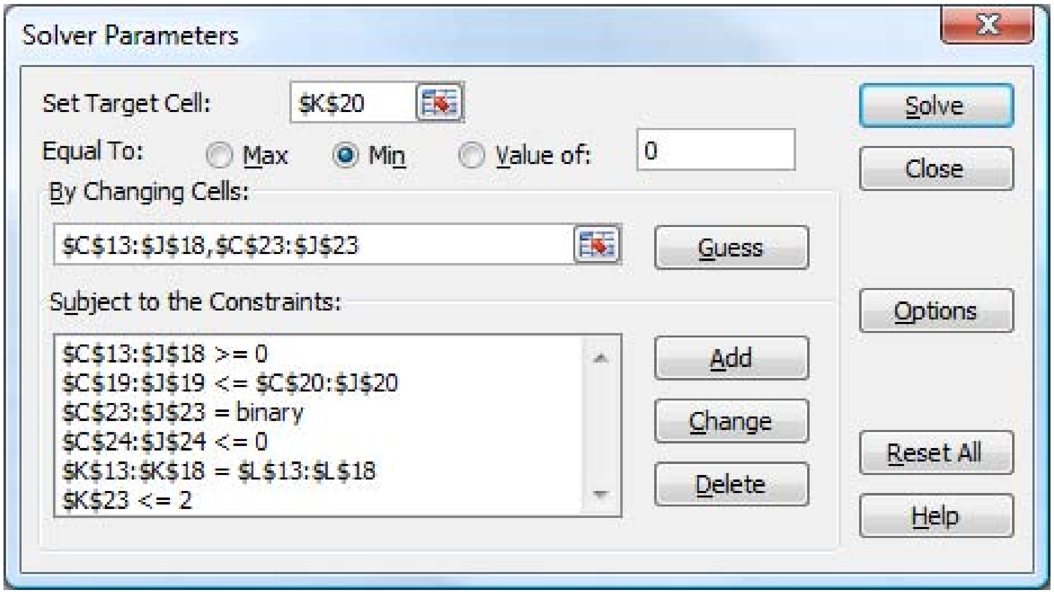


Figure 11. Solver Parameters with Training Location Quantity Constraint

In addition to the constraints shown previously in Figure 8, three more constraints are needed to limit the quantity of training locations used in the model. The first constraint limits the binary variables (cells C23-J23) to assume only binary values. The second constraint ensures the linking relationships discussed above (cells C24-J24) are less than or equal to zero. Finally, we limit the summation of our binary variables (cell K23) to be less than or equal to a number of our choosing *D.*

As evidenced in Figure 12 below, limiting the problem to two supply locations increases total travel costs by $9000, as the end-users from Luiz Munoz and Hanscom AFB travel to Hill ALC and Robins ALC rather than Volk Field CRTC and Hanscom ALC, respectively. Likewise, when we limit the model to a single supply location, all 96 available end-users travel to Robins ALC for a minimum cost of $110,690. Although this is the least expensive alternative when limited to a single supply location, it is more than $19,000 greater than the optimal solution using four locations.

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
Hanscom AFB	1578	1008	1645	1369	1333	0	1065	863
MacDill AFB	1458	1466	1423	1181	895	1209	1015	829
Luis Munoz	1841	1662	2017	1395	1657	1567	1759	1759
Ellsworth AFB	2032	2040	1621	1715	1135	1661	2113	1403
Col Bud Day Field	1474	1732	1983	1331	1873	1553	1947	1095
Joe Foss Field	1376	1634	1885	1233	1775	1455	1849	997

Demand Location	Supply Location								Trainees Sent	Trainees Available
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins		
Hanscom AFB	0	0	0	0	0	0	0	8	8	8
MacDill AFB	0	0	0	0	0	0	0	30	30	30
Luis Munoz	0	0	0	0	8	0	0	0	8	8
Ellsworth AFB	0	0	0	0	35	0	0	0	35	35
Col Bud Day Field	0	0	0	0	0	0	0	8	8	8
Joe Foss Field	0	0	0	0	0	0	0	7	7	7
Trainees Received	0	0	0	0	43	0	0	53	Minimum Total Cost	
Training Capacity	224	182	343	91	147	287	434	931	$100,494	
									Binary Sum	
Binary Variables	0	0	0	0	1	0	0	1	2	
Linking Constraints	0	0	0	0	-53	0	0	-43		

Figure 12. Pilot/IOT&E Phase's Optimal Solution Limited to Two Supply Locations

We proceed in this manner, changing demand levels and capacity levels, as well as the number of available supply locations, with each model replication to determine a wide range of possible outcomes, and their monetary differences with respect to travel cost. The problem we address in this research currently has many unknowns, but our methodology of repetition is in itself a sensitivity analysis that can help answer "what if" questions. This approach provides decision makers with a quantitative basis to potentially decide where organic ILT training should be provided, or perhaps indicates other areas for potential research and analysis.

Table 3 below shows how the information gathered from each model replication is recorded in Appendices C-K. This particular table shows the optimal solutions for the Pilot/IOT&E phase, if the training facilities can dedicate 10% of their training capacity to

ECSS. Training demand increases in intervals of 10%, reaching a maximum of 90%, as CSC is contracted to provide ILT to the remaining 10% of all end-users. The “Optimal” column indicates the cost minimizing supply locations, and their associated travel cost, with no limitation on the number of facilities used. The remaining columns, labeled “2 Locations,” and “1 Location,” show the cost minimizing supply locations, and their associated travel costs, when restricted to a maximum of two installations and one installation, respectively. In addition, these columns indicate the difference in cost (Δ) from those solutions in the “Optimal” column.

Table 3. Pilot/IOT&E Phase Optimal Solutions Given a 10% Training Capacity

10% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	4,5,6,8	91	5,6,8	93	1	5,8	100	9	8	111	19
20%	4,5,6,8	180	5,6,8	182	3	5,8	197	17	8	217	37
30%	4,5,6,8	269	5,6,8	272	4	5,8	293	25	8	323	55
40%	4,5,6,8	357	5,6,8	362	5	5,8	391	35	8	429	73
50%	4,5,6,8	453	5,6,8	460	6	5,8	498	45	8	537	84
60%	4,5,6,8	551	5,6,8	559	8	6,8	598	47	8	644	93
70%	4,5,6,8	649	5,6,8	658	9	6,8	697	48	8	750	101
80%	4,5,6,8	747	5,6,8	757	10	6,8	796	49	8	857	110
90%	4,5,6,8	845	5,6,8	856	11	6,8	895	51	8	963	118
* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

Chapter Summary

In this chapter, we restated our research problem of determining the travel cost minimizing supply locations for ECSS ILT. We then explained the data and assumptions used to determine the pertinent elements of our linear programming model, to include the decision variables, objective function coefficients, objective function, constraints, and lower bounds. In addition, we detailed where we obtained the data for our research. Finally, we explained how we create our model using Microsoft® Excel Solver, and

through replication obtain useful results despite facing many unknowns, particularly demand and supply capacity constraints.

Chapter IV: Results and Analysis

Overview

In this chapter, we analyze the results from our research methodology discussed in Chapter III. We begin with a comparison between the travel costs for worst-case scenarios and the travel cost minimizing solutions determined using our linear programming model to estimate the potential monetary impact of our research. Next, we restate the research questions posed in Chapter I, and describe, using a sample of the results from our linear programming model, how the tables in Appendices C-K can answer these questions with respect to each of the nine training phases. Finally, we discuss how the overall results of our model indicate which supply locations should, and should not, be considered for each training phase.

Potential Impact

In Chapter I, we mentioned how personnel travel is oftentimes overlooked in discussions on cost saving strategies within the Department of Defense. We also stated, presumably, that analyzing transportation networks, as we have done in this research effort, might indicate how the Department's overall travel costs can be significantly reduced. Of course, the definition of significance in regards to cost savings is relative to the person or organization that benefits from such savings, but upon analysis of the results from our linear programming model, it is evident that our presumptions were well founded.

Figure 13 below shows the estimated potential cost savings if 10% of ECSS end-users are trained at the locations identified by our model. The minimum values in the

graph represent the optimal solutions of our model for each phase, given a demand level of 10%, and ideal capacity. The maximum values then, are the antithesis of the minimums, or the worst-case scenarios, given a demand level of 10%, and ideal capacity. We calculate these maximum values by finding the maximum, rather than minimum, solution to our objective function. Using the Solver software discussed earlier, this is simply selecting the "Max" option under the "Equal to:" prompt when defining the model's parameters.

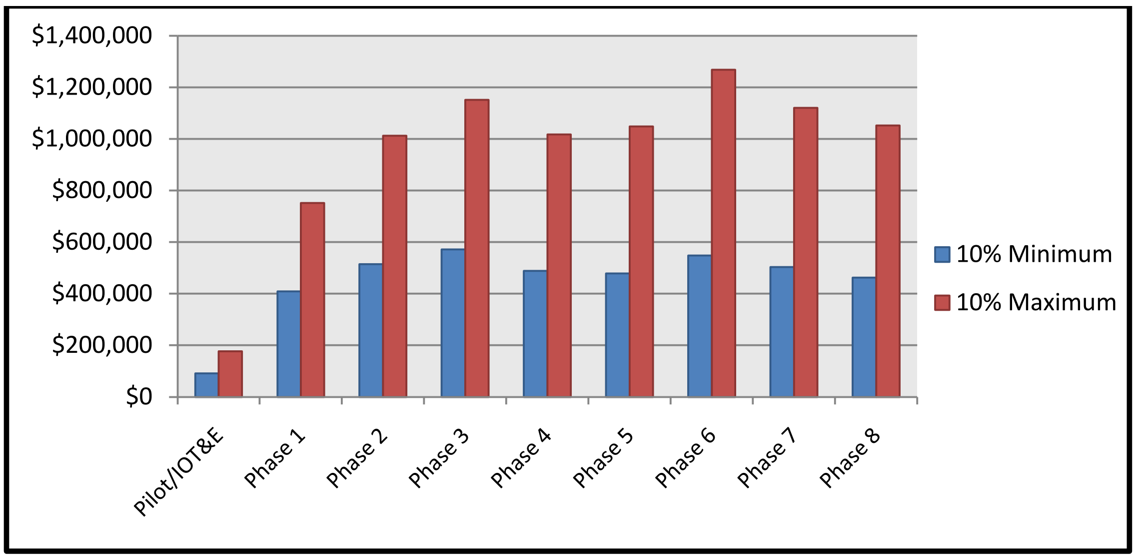


Figure 13. Minimum vs. Maximum Travel Costs for 10% Training Demand

In this instance, Phase 1 of the training represents the minimum percentage difference between potential minimum and maximum travel costs. According to our model, $409K is the minimum travel expense required to provide ILT to 10% of the end-users in this phase. On the other hand, our model calculates a maximum of $751K to train these same end-users, a total that is nearly 84% more costly than the minimum

solution. Meanwhile, Phase 6 represents the maximum percentage difference between any of the paired minima and maxima in Figure 13. In this training phase, the maximum travel expense of $1.27M is approximately 132% greater than the potential minimum cost of $558K. In total, the primary training phases (Phase 1-8) have maximum possible costs that are an average of 111% greater than the potential minimum solutions, which equates to approximately $4.5M.

Although the percentage change between travel cost minima and maxima in the example above are considerably high, the actual dollar difference per phase is less than $1M; a figure that many would consider insignificant when compared to the Air Force's total annual budget. However, the same percentage changes discussed above are comparable to scenarios involving larger quantities of travelers, which equate to larger monetary values. Figure 14 below illustrates this point, showing the potential differences in minimum and maximum travel expenses given an ILT demand level of 90%.

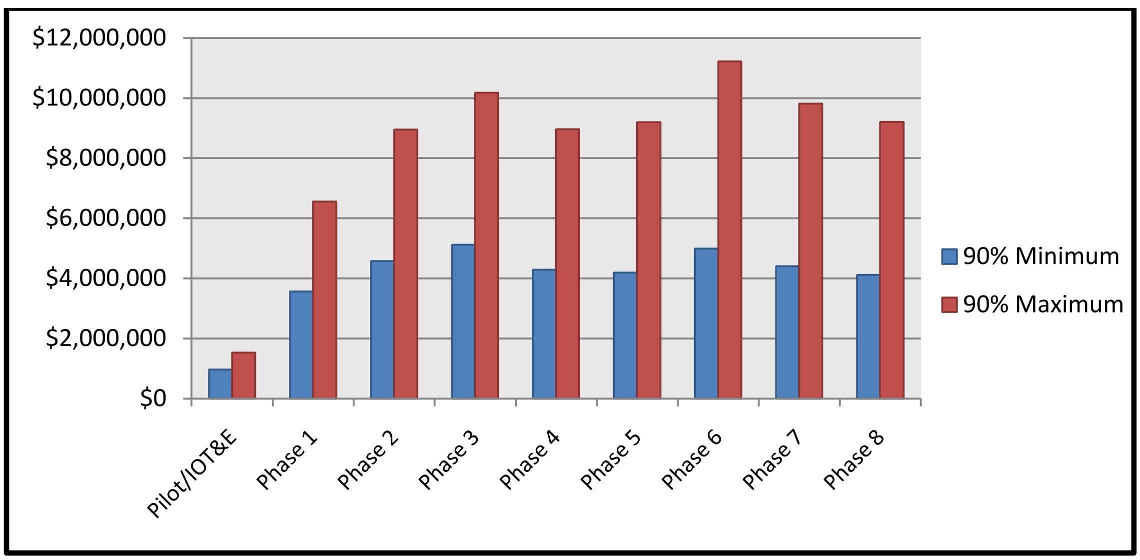


Figure 14. Minimum vs. Maximum Travel Costs for 90% Training Demand

Similar to the 10% demand scenario discussed above, Phases 1 and 6 are the primary training phases that have the smallest and largest differences, respectively, between their potential minimum and maximum travel costs. In this instance, the maximum cost for Phase 1 is $6.56M, roughly 84%, or $2.99M, greater than the minimum cost of $3.57M. Similarly, the maximum cost for Phase 6 end-users to travel and receive ILT at the potential training locations is $11.22M, nearly 125% greater than the potential minimum cost of $4.99M; a difference of more than $6.22M. Across all primary training phases, the maximum travel costs exceed the minimum solutions by more than 110%, and total to approximately $39.4M.

In each phase of training, regardless of demand levels, the large disparity between the minimum and maximum costs indicates that location selection does affect how much the Air Force spends on personnel travel. Although it is unlikely that end-users would be allocated in such a manner to attain the maximum costs, it is conceivable that training locations selected without travel expense considerations could result in costs that far exceed the possible cost minima found using our model. Therefore, in the following sections of this chapter we discuss how the information gathered from our model can be used to not only answer the research questions that guided this study but also to identify how decision makers can take advantage of the apparent travel cost saving opportunities indicated in Figures 13 and 14 above.

Research Questions Revisited

In Chapter II, we discussed past research that indicated ILT was preferred and presumably superior to all other types of training methods when implementing complex

ERP systems like ECSS. Therefore, our first research question below concentrates on the goal of providing ILT to a wide possible range of end-users. However, in formulating this question, we assume that measures to reach ideal supply capacities, if necessary, are viable. Our second research question then, complements the first by recognizing supply capacities are not likely to be ideal, and that satisfying various levels of demand to the globally dispersed ECSS end-users may be fiscally challenged given the constrained nature of the Air Force's O&M budget. In short, we want to determine what training locations and supply capacities minimize travel costs associated with providing the Air Force's ECSS end-users instructor led training. Below are the research questions, as stated in Chapter I.

1. Given various levels of demand for instructor led training (ILT), and ideal supply capacities at potential ECSS training facilities, which supply location(s) minimize O&M travel costs for the Air Force?
2. What are the supply capacity thresholds at the potential ECSS training facilities that dictate the aforementioned travel cost-minimizing location(s)?

Phase 3 Results and Analysis

At the end of Chapter III, we demonstrate how the results of our linear programming model are recorded in the tables found in Appendices C-K. In this section, we analyze a sample of these results from Phase 3 to answer our research questions and exhibit how our findings can aid decision makers in determining which supply locations, if used, can potentially minimize travel costs.

Phase 3 is the third of eight primary training phases scheduled for Release 1 of the ECSS implementation. In total, approximately 5,481 ECSS end-users at eighteen CONUS and five OCONUS demand locations are targeted to receive training in this phase. Table 4 below indicates the optimal solutions for Phase 3, given the potential supply locations can dedicate 60% of their training capacity to ECSS end-users.

Table 4. Phase 3 Optimal Solutions Given a 60% Training Capacity

60% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,7,8	572	5,7,8	582	10	7,8	641	69	7	741	169
20%	1,5,7,8	1,133	5,7,8	1,153	20	7,8	1,271	137	7	1,468	335
30%	1,5,7,8	1,691	5,7,8	1,720	29	7,8	1,896	205	7	2,190	498
40%	1,5,7,8	2,259	5,7,8	2,305	46	7,8	2,524	265	7	2,915	656
50%	1,5,7,8	2,843	5,7,8	2,903	60	7,8	3,158	315	8	3,831	988
60%	1,5,7,8	3,429	5,7,8	3,500	71	7,8	3,781	352	8	4,588	1,159
70%	1,5,7,8	4,018	5,7,8	4,101	83	7,8	4,407	389	8	5,348	1,330
80%	1,5,7,8	4,613	5,7,8	4,708	95	7,8	5,034	421	8	6,109	1,496
90%	1,5,7,8	5,225	5,7,8	5,331	106	7,8	5,678	453	8	6,872	1,647

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

Sensitivity to Supply Location Quantity

From Table 4 it is evident that, regardless of the demand for ILT, Gulfport CRTC, Hill ALC, Tinker ALC and Robins ALC result in the lowest travel costs when they are effectively used as training locations. Furthermore, we can deduce that these optimal solutions are relatively insensitive to minor changes in the number of training locations used. For example, in this instance, our model indicates that approximately $572K is the minimum amount required to send 10% of ECSS end-users to receive ILT. However, when this optimal scenario is limited to a maximum of three training locations, rather than the optimal four, the minimum travel cost increases by $10K, or 1.7%, and Gulfport is eliminated from the solution. Likewise, when demand for ILT is 90% and a maximum

of three training locations are used, the resulting minimum cost is only $106K, or 2%, greater than the optimal solution when using four locations.

Despite minimal sensitivity to the reduction of a single training location, travel costs can dramatically increase when larger decreases are made in the number training locations used. Considering the 10% demand scenario discussed above, if the maximum number of training locations used drops to two or one, the optimal solution's travel costs increase by $69K and $169K, or 12% and 29%, respectively. Similarly, for the 90% demand scenario a reduction in facility locations from four to one increases travel costs by nearly 32%, or roughly $1.65M.

In such instances, decision makers must weigh the non-travel costs associated with preparing an additional training facility with the travel costs associated with not preparing an additional training facility. In other words, for the 90% demand scenario above, if the costs of preparing three additional training facilities to accommodate ECSS end-users exceed the $1.65M difference in travel costs, then the Air Force is financially better off using Robins as the sole supply location for Phase 3 training. However, if facility preparation costs total less than $1.65M, it would benefit the Air Force, monetarily, to use more than one training location.

Although it intuitively makes sense to choose the number of training facilities that minimize the sum of travel and non-travel costs, other factors often force decision makers to select costlier alternatives. For example, the number of personnel available to train ECSS end-users may limit the number of training locations to be used, regardless of how much it increases overall travel costs. In such instances, the results of our research approach can still aid decision makers in choosing a training location that saves Air Force

O&M dollars. Figure 15 below illustrates how sensitive the optimal solution travel costs for Phase 3 are to the number of locations used given 20%, 50%, and 80% demand for ILT. In addition, Figure 15 shows the Phase 3 worst-case scenarios, similar to those discussed earlier in this chapter, for the demand levels just mentioned. By simple visual inspection, it is evident that even the most costly optimal solutions using a single supply location are still considerably less than what could potentially be spent on travel if end-users were not effectively allocated among travel cost minimizing training locations.

Figure 15. Facility Quantity Effect on Optimal Solution Travel Costs vs. Worst-Case

Of particular interest, regarding Figure 15 is the comparison between the optimal solutions using more than one training location for 80% demand and the worst-case scenario for 50% demand. The relationship between these scenarios suggests that the travel costs incurred to train 50% of end-users could exceed the minimum travel costs required to train 80% of end-users if supply locations are not chosen in a manner that reduces travel expenses. In other words, if the results of our model are ignored, it is

possible that the travel costs required to train 2,740 (50%) Phase 3 end-users could exceed the minimum travel costs required to train 4,385 (80%) end-users, a difference of more than 1,640 end-users. This supports our earlier discussion regarding the potential monetary impact of our research. As the Air Force and other Department of Defense components posture for a prolonged period of fiscal constraint, it is important to recognize these cost saving opportunities and exploit them.

Sensitivity to Supply Location Capacity

In addition to being sensitive to the number of training facilities used, the optimal solutions determined using our linear programming model indicate responsiveness to changes in supply location capacity. Table 5 below lists the optimal solutions for Phase 3, given the potential supply locations can dedicate 50% of their training capacity to ECSS end-users. Upon analyzing this table, we recognize that many of the optimal solutions, and their associated travel costs, are identical to those listed in Table 4. For example, the optimal solutions, given 10% and 20% demand, result in travel costs totaling approximately $572K and $1,133, respectively, regardless if the training capacity at the optimal locations is 60% or 50%.

Table 5. Phase 3 Optimal Solutions Given a 50% Training Capacity

50% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,7,8	572	5,7,8	582	10	7,8	641	69	7	741	169
20%	1,5,7,8	1,133	5,7,8	1,153	20	7,8	1,271	137	7	1,468	335
30%	1,5,7,8	1,693	5,7,8	1,727	33	7,8	1,896	203	7	2,190	496
40%	1,5,7,8	2,269	5,7,8	2,317	47	7,8	2,524	255	8	3,063	793
50%	1,5,7,8	2,864	5,7,8	2,924	60	7,8	3,158	294	8	3,831	967
60%	1,5,7,8	3,450	5,7,8	3,521	71	7,8	3,781	330	8	4,588	1,138
70%	1,5,7,8	4,049	5,7,8	4,132	83	7,8	4,407	358	8	5,348	1,299
80%	1,5,7,8	4,662	5,7,8	4,757	95	7,8	5,067	405	8	6,109	1,447
90%	1,5,7,8	5,277	5,7,8	5,384	106	7,8	5,738	460	Infeasible	n/a	n/a
* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

These identical solutions found in Tables 4 and 5 suggest that lower levels of demand are insensitive to changes in supply capacity, which intuitively makes sense because a small number of trainees are not likely to be constrained by facility capacity. However, as demand increases training capacity at each location has the potential of becoming a binding constraint, which can increase overall travel costs. This is evidenced again using a comparison between Tables 4 and 5 above. The optimal solution for 90% demand, given a 60% training capacity results in travel costs of approximately $5.23M, which is $52K (1%) less than when the scenario is limited to 50% training capacity. Furthermore, if this scenario is limited to a single training facility, 60% supply capacity can satisfy the 90% training demand while minimizing travel costs to $6.87M, whereas a 50% supply capacity fails to satisfy the required demand and an optimal solution is determined infeasible.

The Phase 3 examples discussed above demonstrate two critical points. First, supply capacity can eliminate facility number options and thus reduce the potential choices a decision maker faces. For example, in Phase 3 it is clear that a 50% supply capacity eliminates the option of training 90% of end-users at a single location. Second, the demand scenarios that are feasible across various supply capacities are relatively insensitive to incremental (10%) changes in these supply capacities. Figure 16 below illustrates this point by showing the affect various supply capacity levels have on optimal solution travel costs for demand levels of 20%, 50%, and 80%. In this graph, the largest noticeable increase in travel costs occurs when demand is 80% and supply decreases from 40% to 20%. This change in supply capacity increases travel costs by approximately $324K, or roughly 7%.

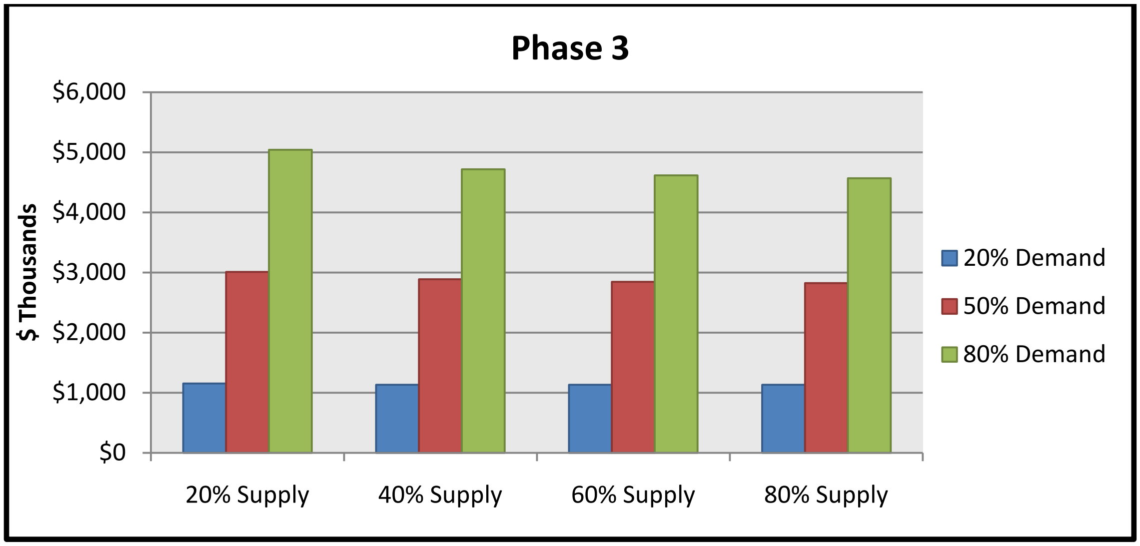


Figure 16. Training Facility Capacity Effect on Optimal Solution Travel Costs

Supply Location Frequency within Optimal Solutions

Our optimal solutions' sensitivity to changes in facility location number and capacity levels discussed in the previous section are encouraging because they are not volatile. In other words, decision makers can be confident the solutions found using our research methodology do not vary randomly when the number of facilities used or the training capacities change. In fact, our analysis of Phase 3 above indicates that the results of our linear programming model follow a seemingly predictable pattern. For example, referring again to Table 5 above, it is evident that if a training location is included in an optimal solution with a restricted number of training facilities, then this same training location is likely to be included in an optimal solution without a restricted number of training facilities. In other words, for a specified level of demand, if an optimal solution exists for a single training location, this same location choice is likely to be included in an optimal solution consisting of two or more training locations. As an example, we can see that when Phase 3 is restricted to a single training location, Tinker ALC or Robins

ALC result in the optimal solution. Then, if the solution is restricted to a maximum of two, three, or four training locations, both Tinker ALC and Robins ALC are also included in the optimal solutions for these scenarios.

With an appreciation for the optimal solutions' predictable nature described above, we analyze the potential supply locations' frequency among the optimal solutions for each training phase to determine which locations are most likely to result in minimizing travel costs for any given scenario. In other words, we determine the number of times each potential training location contributes to the cost minimizing solutions within a given phase. We then graph the frequencies to identify the locations that are most likely to minimize travel costs, regardless of demand and supply levels, or the number of training locations used. Figure 17 below shows, as a percentage, how often each of the eight potential training locations is included in the optimal solutions for each training phase.

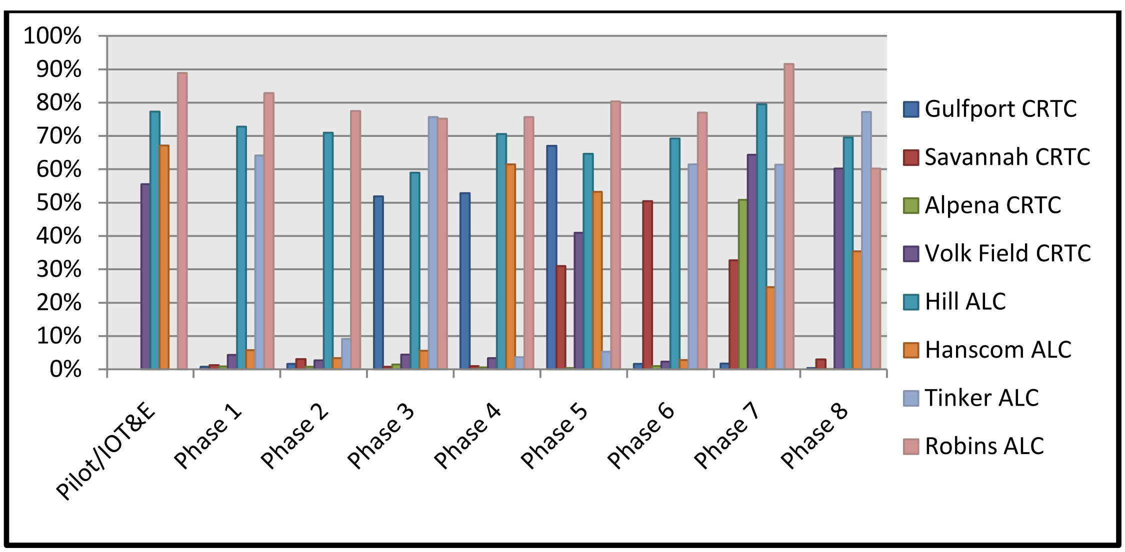


Figure 17. Supply Location Frequency within Optimal Solutions across All Phases

From this graph, it is clear that some locations contribute to the travel cost minimizing solutions more often than others do. For example, Robins ALC and Hill ALC are present in an average of 79% and 70%, respectively, of the optimal solutions, while Savannah CRTC and Alpena CRTC are only present in an average 14% and 6% of the optimal solutions, respectively. However, these averages are aggregated across all phases, which can hide the ability of certain locations, like the CRTCs at Savannah and Alpena, to contribute to minimizing travel expenses within a single training phase. Figure 18 below illustrates this point. Across all phases, Gulfport CRTC is found in only 20% of the optimal solutions determined by our linear programming model. However, as evidenced in the graph, Gulfport CRTC can help minimize travel costs significantly in training Phases 3, 4, and 5, where it is found in 57% of our model's optimal solutions. In addition, this figure indicates when Gulfport CRTC should be avoided. In the phases where its frequency is near 0%, the use of Gulfport CRTC is likely to increase overall travel expenses, and other locations should have priority. Similar graphs for each potential training location are located in Appendix L.

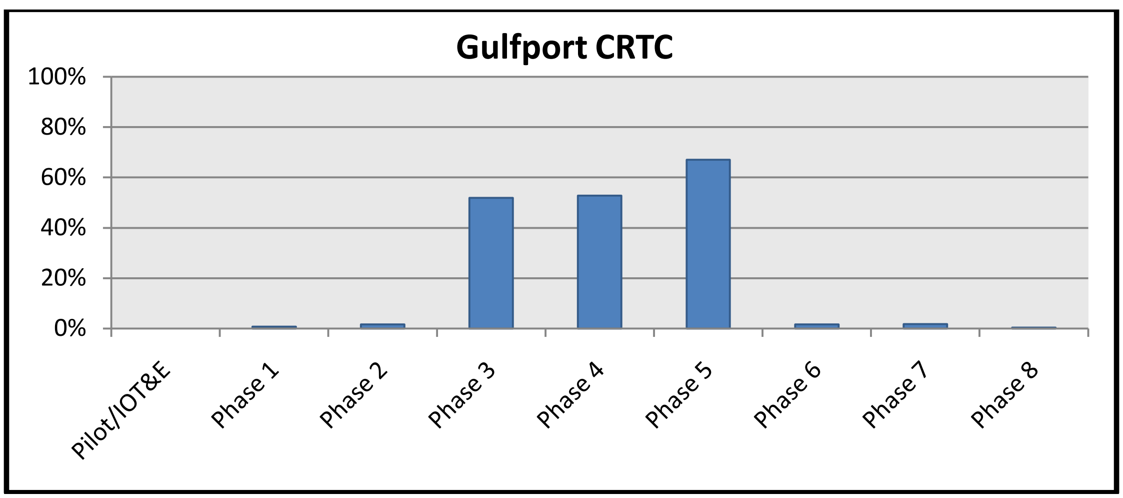


Figure 18. Gulfport CRTC Frequency within Optimal Solutions across All Phases

Although graphs like the one above help identify the phases each potential training location should, or should not, be considered to provide training during, this information must be analyzed within the context of each phase in order to make an optimal decision. For example, in Figure 18 above, it is evident that Gulfport contributes to a significant number of the potential optimal solutions within Phase 3; however, Figure 19 below indicates that other locations should have a higher priority within this phase.

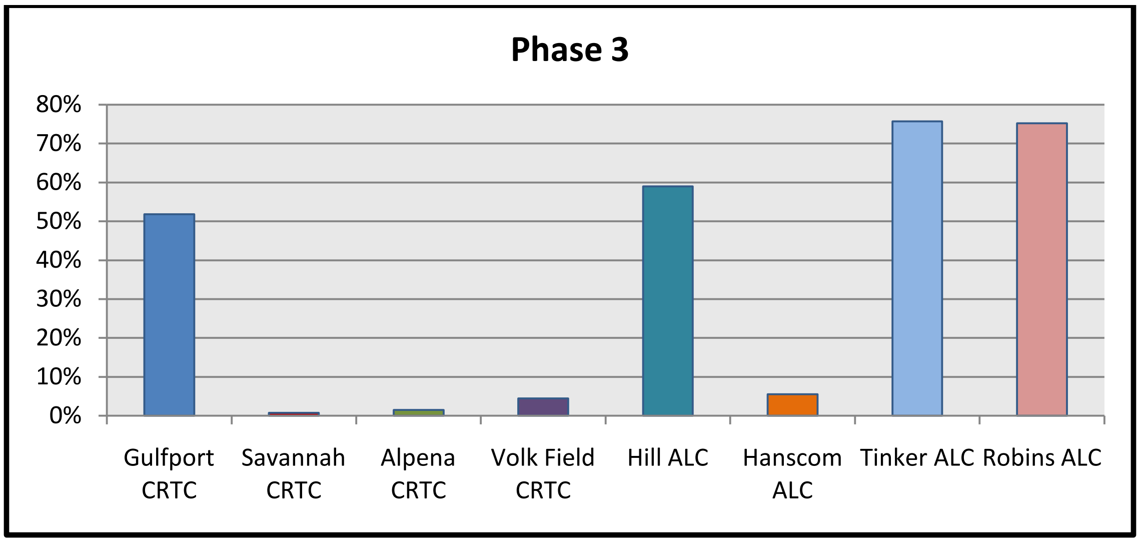


Figure 19. Supply Location Frequency within Optimal Solutions for Phase 3

Furthermore, when compared to the information found in Tables 4 and 5 discussed earlier, we find that Gulfport CRTC only contributes to an optimal solution when four or more training locations are used. Not coincidentally, in this training phase, Gulfport CRTC has the fourth highest optimal solution frequency among all potential training locations. This occurrence corresponds to the predictable nature of the optimal solutions mentioned at the beginning of this section. Put simply, the location most frequently found among the optimal solutions within a phase, represented by the tallest

bar within the graph, corresponds to the majority of optimal solutions for scenarios limited to a single training location; the tallest two bars correspond to the majority of optimal solutions for scenarios limited to two training locations, and so on.

Graphs like Figure 19 are undoubtedly beneficial to our analysis, as they provide a snapshot of the travel cost minimizing supply locations for each training phase and indicate the optimal location choice when the number of training facilities used is restricted. Similar graphs for each training phase are located in Appendix M, and can be used to compare various scenarios for each of the ECSS Release 1 training phases, as we have done in this chapter for Phase 3.

Chapter Summary

In this chapter, we discussed the potential monetary impact of our findings, and determined that our research can create value for the Air Force. Specifically, our research approach indicates that determining the travel cost minimizing training locations can potentially reduce overall training costs and help alleviate some of the financial pressures of operating in a fiscally constrained environment. Next, using results from Phase 3 as an example, we showed how the information gathered from our models, and recorded in Appendices C-K, can be referenced to determine which training locations should be used given various levels of demand for ILT, supply capacities at potential training locations, and quantities of supply locations to be used. In addition, we examined a sample of the Phase 3 results' sensitivity to changes in supply location quantity, and supply location capacity to determine how the optimal solutions are affected. Finally, we summarized the results of our model using graphs that indicate the

potential supply locations’ frequencies within each training phases optimal solutions. These graphs provide decision makers a means to determine visually the supply locations that will most likely result in minimum travel costs, regardless of demand and capacity levels.

Chapter V: Conclusions

Overview

In this final chapter, we briefly summarize the overall findings of our study with a general recommendation for each of the training phases within Release 1 of the ECSS implementation. We then discuss potential shortcomings inherent in our model assumptions. Finally, we close with a discussion on areas for future research.

Recommendations

When we discussed our research methodology in Chapter III, we emphasized the importance of determining the ECSS training locations that minimize travel costs across many different scenarios (i.e. various levels of supply, demand, and facility quantity) because the current training situation is riddled with unknowns. Specifically, the number of end-users to receive organic ILT and the true supply capacities at potential training locations are yet to be determined. In addition, these unknowns make it difficult to calculate how many training locations should be used to minimize travel costs.

Given these uncertainties, it is impossible to provide exacting recommendations for any of the training phases discussed throughout this research. However, through the analysis of our linear programming model results, discussed in Chapter IV, we have identified several locations that stand out as travel cost minimizing alternatives across all training phases. We use these locations, and assume conservative demand and supply levels, to formulate general recommendations that can guide decision makers until more information about true training demand levels and supply capacities becomes available.

Table 6 below summarizes our recommended supply locations for each of the nine training phases scheduled for Release 1.

Table 6. Recommended Locations for Organic ECSS ILT

Recommended Training Locations	
Pilot/IOT&E	Robins, Hill, Hanscom
Phase 1	Robins, Hill, Tinker
Phase 2	Robins, Hill
Phase 3	Robins, Hill, Tinker
Phase 4	Robins, Hill, Hanscom
Phase 5	Robins, Hill, Hanscom
Phase 6	Robins, Hill, Tinker
Phase 7	Robins, Hill, Hanscom
Phase 8	Robins, Hanscom, Tinker

The recommendations listed above are grounded on four key assumptions. First, we assume a training demand of 60%, which encompasses all ECSS super users, and regular users, as described in Chapter III. Second, we assume a modest 30% of the training capacity at each training location will be available to train ECSS end-users. Third, we assume that during this initial stage of the ECSS implementation, organic expertise will be limited and a small number of available instructors will restrict training to a maximum of three locations for any given phase. Finally, we assume that classroom preparation costs are substantial and no more than four locations will be configured to accommodate ECSS ILT training.

Despite assuming only a 30% training capacity and a maximum of three training locations for each phase, our recommendations are very comparable to the optimal solutions that would result if all eight potential training locations were used. Figure 20 below illustrates how well our recommendations fare against the optimal and worst case

scenarios, given equal demand levels and supply capacities. On average, our recommended solutions for each phase are $86K, or 3%, more expensive than the optimal solutions. This equates to a total of approximately $772K across all phases. In addition, our recommended solutions are an average of $2.65M, or 48%, less expensive per phase than the worst-case scenarios. This difference totals to roughly $23.8M across all phases.

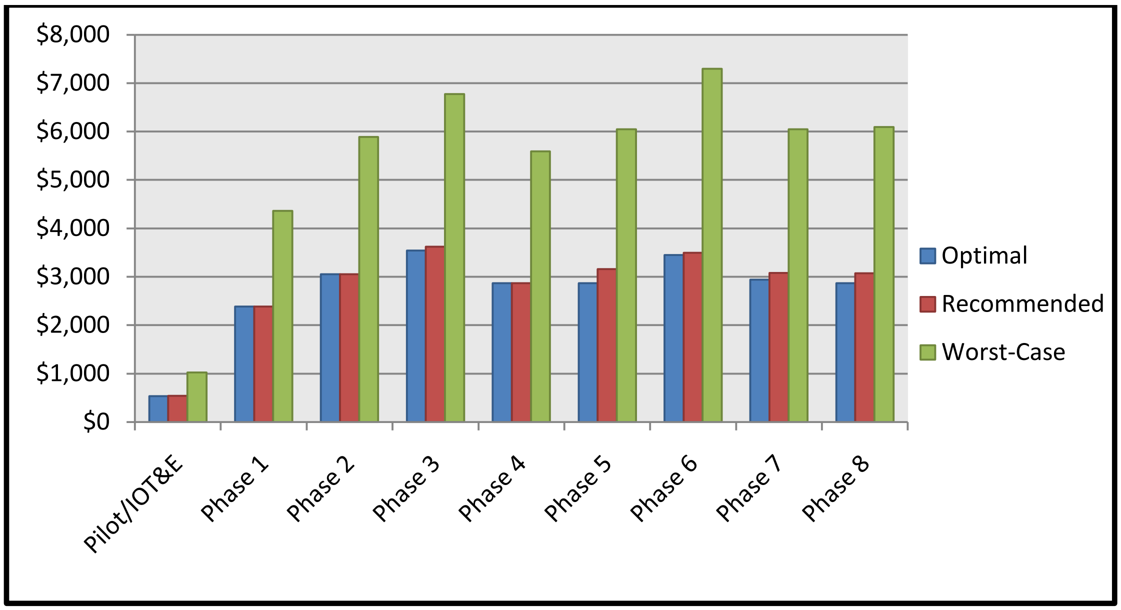


Figure 20. Recommended Solutions vs. Optimal and Worst-Case Solutions

Besides mirroring the optimal solutions with a minimum number of training facilities, our recommended solutions also make logical sense for two reasons. First, the four training destinations recommended, Robins, Hill, Hanscom, and Tinker, are all ALCs. These logistics centers, based on their mission, are more likely than the CRTC locations to have training capacity available to train ECSS end-users. The CRTC locations not included in our recommendations provide training to service members prior

to deployments, which means the available capacity at these locations are dictated by the operations tempo at forward deployed locations. Due to the fact that wartime operations are unpredictable, it would be difficult to accurately forecast classroom availability at these CRTCs.

In addition to having a more stable training schedule, the ALCs in our recommended solutions require all end-users traveling by air to fly into densely populated metropolitan areas with large international airports. These large airports, due to their high volume of air traffic, typically demand lower airfares from its travelers. Thus, it is likely that end-users traveling to our recommend training locations (via airports in Atlanta, GA; Salt Lake City, UT; Boston, MA; and Oklahoma City, OK) will pay less airfare than those travelers flying to the CRTC locations (via airports in Gulfport, MS; Savannah, GA; Alpena, MI; and La Crosse, WI).

Shortcomings of the Model and Assumptions

As discussed earlier, the problem addressed in this research currently has many unknowns. Therefore, in order to create a model that can provide decision makers insight into what potential ECSS training locations can minimize travel costs, we needed to make several necessary, although flawed, assumptions.

First, we assume that all ECSS end-users are Department of Defense employees and if necessary, only travel on government contracted flights. Although federal regulations theoretically support this assumption, in reality it is relatively easy for travelers using DTS to select flights that are not under government contract. Thus, the accuracy of this assumption remains questionable without evidence that indicates the

end-users at the demand locations in our model travel to the supply locations using only government contracted flights.

Second, due to the unknown ratio of military-to-civilian end-users, we assume that all trainees will receive full per diem when traveling away from their home station. In reality, it is likely that a significant portion of end-users will be active duty military members who will obtain lodging on base and receive proportional, rather than full per diem. This would result in lower travel costs for these end-users, which would in turn alter the values of the objective function coefficients used in our model.

Third, we assume that end-users would opt to drive a personally owned automobile, rather than fly, to attend training if their home station is within 250 miles of a potential training location. As mentioned in Chapter III, the mode of transportation chosen by the end-user is dictated by personal preference, which could not be accurately accounted for in our research. It is possible that individuals stationed beyond the 250 radius mentioned above could opt to drive, and it is also possible that individuals within the 250 mile radius could opt to fly. In either of these cases, our assumption does not accurately capture the end users' travel costs, which could again alter the values of our model's objective function coefficients.

Fourth, we ignore the possibility that some end-users may be authorized to use rental cars at their training destinations. Policy on rental car use during temporary duty assignments typically varies from unit to unit, and is therefore difficult to estimate. However, rental car use can significantly increase an end-user's overall travel costs. In this case, similarly to the assumptions listed above, end-user preference or unit policy can alter the values of the objective function coefficients in our model.

Our final assumption that potentially hinders the accuracy of our model is that both demand for training and supply capacity for a given scenario is constant among all demand and training locations within that scenario. In reality, it is very likely that these percentages will not be constant across all locations. For example, it is possible that each demand location has a different percentage of end-users that require ILT. Similarly, it is possible that some training facilities could have 7% capacity while others have 34% capacity. For this reason, we encourage interested parties to replicate our methodology using accurate demand and capacity percentages when they are known, or reasonably estimated. Doing so will result in solutions that more accurate.

Final Thoughts and Future Research

In this study, we have undoubtedly identified an area of research that should receive more attention; especially in discussions focused on minimizing costs to provide budget flexibility in the Department of Defense's fiscally constrained environment. The results of our analysis indicate that facility location plays a considerable role in determining how much the Air Force and other Department of Defense components spend on personnel travel. If the potential transportation network for ECSS training examined in this research effort is indicative of other transportation networks within the Department of Defense, it is likely that millions of dollars are wasted each year by sending personnel to training locations that do not minimize travel costs.

During its current initiatives to reengineer business processes and maximize efficiency across all organizational levels, the Air Force should also consider examining travel costs from the enterprise level. As discussed in Chapter II, subcomponents of large

organizations often act autonomously to maximize personal efficiencies or cost savings at the expense of the organization as a whole. Thus, by understanding how facility location influences travel expenses across the entire Air Force, decision makers could better allocate missions and responsibilities among those installations that can minimize costs.

One area of particular interest for future research is an analysis of the Air Education and Training Command (AETC) installations' impact on the Air Force's overall travel expenses. AETC trains approximately 340,000 students annually across 12 bases. Using a similar research approach to the one used in this study, one could determine if the training missions of the AETC bases are located in a manner that reduces travel costs to the Air Force. In addition, if it was determined that these missions are not ideally located, one could establish where these training missions should be located when travel costs are considered. Based on the results of our analysis for ECSS training locations, it is likely that significant opportunities for cost savings exist within the much larger AETC transportation network.

Appendix A: Objective Function Coefficients

Pilot/IOT&E

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
Hanscom AFB	1578	1008	1645	1369	1333	0	1065	863
MacDill AFB	1458	1466	1423	1181	895	1209	1015	829
Luis Munoz	1841	1662	2017	1395	1657	1567	1759	1759
Ellsworth AFB	2032	2040	1621	1715	1135	1661	2113	1403
Col Bud Day Field	1474	1732	1983	1331	1873	1553	1947	1095
Joe Foss Field	1376	1634	1885	1233	1775	1455	1849	997

Phase 1

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
Barksdale AFB	1532	1524	1787	1501	1253	1513	1783	1231
Fort Smith ANG	1782	1774	1833	1541	1503	1561	1567	1555
Homestead ARS	1612	1290	1419	1425	1071	1343	1069	785
Willow Grove ANG	1378	1088	1325	1145	1189	1131	919	857
Peterson AFB	1602	1476	1653	1571	1055	1175	1387	1019
Thule AB	1491	1208	1627	1319	1199	1235	1111	957
Vandenberg AFB	1600	1508	2037	2003	1137	1419	1473	1239
Fresno-Yosemite ANG	1462	1382	1789	1491	1169	1461	2037	1129
Moffett Field ANG	1548	1594	1853	1653	777	1395	1045	923
Channel Islands ANG	1320	1228	1757	1723	857	1139	1193	959
USAF Academy	1602	1476	1653	1571	1055	1175	1387	1019
Wright-Patterson AFB	1724	1132	1529	1277	967	1143	991	765
Springfield ANG	1724	1132	1529	1277	967	1143	991	765
Rome Lab/Griffiss AFB	1381	1239	1798	1270	1548	1122	1232	1100
Rickenbacker ANG	1556	1442	1455	1727	893	1047	917	829
Mansfield-Lahm ANG	1644	1530	1543	1815	981	1135	1005	917
Hancock Field ANG	1334	1192	1751	1223	1501	1075	1185	1053
Youngstown	1602	1488	1835	1375	1035	1251	1087	853
Dobbins AFB	1248	1256	1391	1201	1411	1167	1425	742
CPSG	1412	1404	1593	1361	1135	1239	1001	883
Kelly ANG	1412	1404	1593	1361	1135	1239	1001	883
Ellington Field	1402	1230	1975	1245	1003	1183	981	1175
Brooks City Base	1412	1404	1593	1361	1135	1239	1001	883

Phase 2

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
Scott AFB	1197	1363	1510	1534	1230	1650	994	846
Springfield IL ANG	1658	1302	1491	1199	1095	1299	1161	1013
Fort Wayne ANG	1638	1252	1441	1149	1045	1249	1111	1285
Grissom ARB	1400	1716	1783	1743	955	1349	955	903
Toledo ANG	1706	1516	1705	1413	1309	1513	1375	1873
Langley AFB	1692	1446	1773	1999	1771	1313	1257	809
Byrd Field ANG	1620	1216	1601	1393	1373	1113	1123	809
Lambert Field	1160	1326	1473	1497	1193	1613	957	809
Minot AFB	2474	1924	2221	2071	1765	2157	2061	1615
Hickam AFB	1928	2446	1855	1543	1149	1561	2315	1555
Lajes Field AB	1491	1208	1627	1319	1199	1235	1111	957
Randolph AFB	1412	1404	1593	1361	1135	1239	1001	883
Lackland AFB	1412	1404	1593	1361	1135	1239	1001	883
Fort Rucker	1860	1868	2003	1655	2015	1877	1725	1231

Phase 3

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
Dover AFB	1414	1124	1361	1181	1225	1167	955	893
New Castle ARB	1366	1076	1313	1133	1177	1119	907	845
Westover ARB	758	1756	1799	1285	971	1009	1049	1349
Stewart ANG	1368	1214	1481	1533	1233	1061	989	865
Fairchild AFB	1466	1448	1681	1775	1033	1363	1113	1297
March ARB	1768	1730	1707	1415	949	1853	1345	1789
Reno-Tahoe ANG	1462	1370	1861	1483	873	1437	1211	1145
Holloman AFB	1804	1542	2047	1605	891	1317	1035	1397
Aviano AB	3027	1888	3239	1739	2851	1869	1535	2833
Akrotiri	1491	1208	1627	1319	1199	1235	1111	957
Sembach AB	2992	1669	2030	1610	1050	1814	1262	1266
Elmendorf AFB	1754	1660	2763	1697	2301	1873	2147	1395
Anchorage ANG	1754	1660	2763	1697	2301	1873	2147	1395
Malmstorm AFB	2258	1964	2071	2165	1135	1863	1493	1629
Great Falls ANG	2258	1964	2071	2165	1135	1863	1493	1629
Kirtland AFB	1428	1502	1457	1371	1125	1185	1025	1395
Luke AFB	1418	1728	1505	1195	831	1473	1277	881
Sky Harbor ANG	1418	1728	1505	1195	831	1473	1277	881
Goodfellow AFB	1476	1468	1151	1445	1197	1669	1261	1063
Maxwell AFB	864	1868	2003	1867	1517	2051	1383	774
Birmingham ANG	1756	1754	1613	1885	1137	1895	1519	838
Dannelly Field ANG	858	1868	2003	1867	1517	2051	1383	780
Key Field ANG	872	1856	1657	1461	1477	2199	1355	1337

Phase 4

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
Andrews AFB	1014	1040	1477	871	1083	1033	961	793
Baltimore ANG	1014	1040	1477	871	1083	1033	961	793
Pentagon	1014	1040	1477	871	1083	1033	961	793
Bolling AFB	1014	1040	1477	871	1083	1033	961	793
Charlotte ANG	1822	2030	1605	1173	1145	1293	985	751
Seymour Johnson AFB	1489	1497	1716	1232	1128	1218	1088	860
New Orleans NAS JRB	717	1342	1747	1269	951	1203	1241	735
Burlington ANG	1606	1614	1713	1559	1455	1086	1423	977
Francis S Gabreski ANGB	1382	1228	1495	1547	1247	1075	1003	879
Stratton ANGB	1710	1500	1915	1329	1369	1056	1535	1331
Christschurch	1491	1208	1627	1319	1199	1235	1111	957
Niagara Falls ANG	1748	1250	1931	1193	1489	1153	1351	851
Bangor ANG	1960	1968	1551	1843	1349	1118	1741	1331
Pease ANG	1642	1072	1709	1433	1397	1003	1129	927
FE Warren AFB	1468	2140	1479	1311	779	1463	1127	967
Cheyenne ANG	1469	2141	1480	1312	780	1464	1128	968
Buckley ANG	1360	2032	1371	1203	671	1355	1019	859
Eglin AFB	809	1428	1967	1517	1081	1233	1149	791
Arnold AFB	1405	1393	1684	1336	984	1266	1332	1420
Hurlburt Field AFB	795	1428	1967	1517	1081	1233	1149	791
Andersen AFB	3343	3344	3767	3697	2809	3699	3163	2839
Utapao IAP	2634	2687	2902	2682	2214	2800	2584	2068
Diego Garcia	1491	1208	1627	1319	1199	1235	1111	957
Eielson AFB	2114	2020	2389	2097	2661	2233	2507	1755

Phase 5

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
McGuire AFB	1385	1095	1332	1152	1196	1138	926	864
Atlantic City ANG	1394	1104	1341	1161	1205	1147	935	873
Quonset ANG	1314	1346	1729	1313	1275	950	1261	1307
Harrisburg ANG	1800	1162	1893	1329	1545	1483	1321	1231
McConnell AFB	1452	1460	1659	1367	1921	1241	1329	823
Forbes Field ANG	1508	1230	1767	1235	1169	1499	1601	879
Davis Monthan AFB	1508	1594	1471	1683	833	1383	1317	957
Soto Cano AB	1906	2335	2284	1776	2018	2096	1886	1704
Curacao AB	1909	1962	2139	1747	1791	1995	1823	1505
Manta AB	2024	2077	2254	1862	1906	2110	1938	1620
Tucson ANG	1508	1594	1471	1683	833	1383	1317	957
Mountain Home AFB	1469	1571	1768	1550	1084	1650	1416	1220
Boise ANG	1418	1520	1717	1499	1033	1599	1365	1169
Whiteman AFB	1538	1260	1797	1265	1199	1529	1631	909
St Joseph ANG	1470	1192	1729	1197	1131	1461	1563	805
Minneapolis-St Paul ANG	1692	1142	1439	1173	983	1375	1279	833
Minneapolis/St. Paul ARS	1692	1142	1439	1173	983	1375	1279	833
Keesler AFB	0	1762	2027	1657	1409	1829	1473	1195
Gulfport ANG	0	1762	2027	1657	1409	1829	1473	1195
Patrick AFB	1468	1512	1493	1333	1363	1259	1107	825
Tyndall AFB	1816	1824	1959	1857	1753	1875	1723	1187
Edwards AFB	1352	1260	1751	1375	889	1171	1101	913
Spangdahlem AB	3037	1714	2075	1655	1095	1859	1307	1311
Kunsan AB	3601	3672	5299	2123	2613	2217	3523	3459

Phase 6

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
Charleston AFB	1602	1450	1769	1689	1625	1467	1769	813
McEntire ANGB	1462	1812	1483	1647	1215	1175	1249	1175
Savannah ANG	1654	0	1699	1329	1745	1151	1857	760
Grand Forks AFB	2288	1736	2033	1767	1577	1969	1873	1907
Hector Field ANG	1534	1542	2121	1829	1581	1595	1469	1415
Duluth ANG	2082	1712	2137	1763	1553	1945	1849	1403
Pittsburgh IAP	1544	1430	1777	1317	977	1193	1029	795
Little Rock AFB	1450	1804	1489	1311	1013	1321	1245	1125
Memphis ANG	1190	1330	1873	1203	1137	1313	1325	753
Greater Peoria ANG	1346	1240	1429	1137	1033	1237	1099	997
Will Rogers ANG	1398	1890	1717	1221	1245	1241	0	1297
Columbus AFB	874	1586	2069	1417	1729	1639	1513	595
Hulman Field ANG	1402	1718	1785	1745	957	1351	957	905
Dyess AFB	1526	1518	1781	1585	1247	1579	1311	1717
Carswell ARS*	1156	1148	1411	1125	877	1349	941	831
Sheppard AFB	1528	1520	1783	1497	1249	1721	1313	1591
Tulsa ANG	1414	1406	1535	1223	929	1323	699	1297
Hill AFB	1500	1944	1491	1321	0	1675	1411	1449
Salt Lake City ANG	1500	1944	1491	1321	0	1675	1411	1449
McClellan AFB	1432	1320	1577	1679	911	1471	1161	1323
Ramstein AB	2992	1669	2030	1610	1050	1814	1262	1266
Moron AB	2039	2058	2275	2197	1741	1855	1839	2869
Kadena AB	1491	1208	1627	1319	1199	1235	1111	957
Los Angeles AFB	1274	1182	1711	1677	811	1093	448	913

Phase 7

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
McChord AFB	1932	1484	1885	1313	907	1383	1013	1135
Portland ANG	1614	1606	1745	1547	1033	1235	985	1549
Kingsley Field ANG	1972	1964	2103	1905	1391	1593	1343	1907
Pope AFB	1644	2212	2813	1415	1371	2873	1409	1175
McGhee Tyson	1728	1878	1989	1209	1487	1201	1647	1241
Yeager	1610	1618	2055	1895	1761	1607	1545	1133
Moody AFB	1265	1037	1662	1650	1626	1294	1230	877
Jacksonville ANG	1124	860	1521	1509	1485	1153	1089	1163
Truax Field ANG	1600	1236	1461	613	1145	1115	1161	981
Volk Field ANG	1748	1740	1985	0	1321	1711	1387	1239
Battle Creek/W K Kellogg	1516	1324	901	1221	1117	1321	1669	887
Alpena	2118	1898	0	1985	1491	1987	1883	1429
Offutt AFB	1566	1282	1425	1179	1235	1227	1141	835
Lincoln ANG	1630	1346	1489	1243	1299	1291	1205	899
Des Moines ANG	1030	1238	2089	1135	1119	1401	1097	835
Altus AFB	1614	1606	1869	1583	1335	1807	1399	1677
Nashville ANG	1334	1322	1613	1265	913	1195	1261	1349
Martinsburg ANG	1102	1128	1565	959	1171	1121	1049	881
Yokota AB	3183	1848	1769	1723	1499	1901	4241	1417
Misawa AB	3763	2428	2349	2303	2079	2481	4821	1997
Incirlik AB	1491	1208	1627	1319	1199	1235	1111	957
Izmir AB	2519	2572	2963	2515	2411	2595	2481	3131
Vance AFB	1480	1972	1799	1303	1327	1323	781	1379
Robins AFB	1286	1294	1429	1239	1449	1205	1463	0
Shaw AFB	1503	1853	1524	1688	1256	1216	1290	1216
Al Udeid AB	9020	8866	9133	9185	8885	8751	8641	8517

Phase 8

Demand Location	Supply Location							
	Gulfport	Savannah	Alpena	Volk Field	Hill	Hanscom	Tinker	Robins
Travis AFB	1480	1368	1625	1701	825	1443	1093	923
Nellis AFB	1404	1320	1531	1235	871	1345	1063	921
Creech AFB	1457	1373	1584	1288	924	1398	1116	921
Beale AFB	1458	1346	1603	1705	937	1497	1187	1323
Laughlin AFB	1571	1563	1752	1520	1294	1398	1160	883
Tinker AFB	1398	1890	1717	1221	1245	1241	0	1297
Cannon AFB	1586	1578	1841	1645	1307	1629	1371	1891
Selfridge ANG	1538	1318	1113	1405	911	1407	1303	849
Standiford Field	1758	1152	1645	1189	1009	1263	1151	1475
Bradley Field ANG	1816	1714	1757	1243	929	985	1007	1307
Bradley Field CIRF	1816	1714	1757	1243	929	985	1007	1307
Barnes ANG	1858	1756	1799	1285	971	1015	1049	1307
Otis ANG	1646	1076	1713	1437	1401	1028	1133	863
RAF Lakenheath	2755	1538	1625	1591	945	1491	1345	2443
RAF Menwith Hill	1945	2004	2389	1783	1995	2021	1907	2443
RAF Fairford	2955	1738	1825	1791	1145	1691	1545	2443
RAF Mildenhall	2755	1538	1625	1591	945	1491	1345	2443
Osan AB	3551	3622	5249	2073	2563	2167	3473	3339
Suwon AB	3601	3672	5299	2123	2613	2217	3523	3339
Kimhae AB	3299	3372	3585	3385	2509	3203	2811	4789
Taegu AB	3369	3442	3655	3455	2579	3273	2881	4789
Kwangju AB	3369	3442	3655	3455	2579	3273	2881	4789

Appendix B: Total End-User Demand

Pilot/IOT&E

Demand Location	End-Users
Hanscom AFB	71
MacDill AFB	294
Luis Munoz	72
Ellsworth AFB	345
Col Bud Day Field	75
Joe Foss Field	69
TOTAL	926

Phase 1

Demand Location	End-Users
Barksdale AFB	573
Fort Smith ANG	73
Homestead ARS	200
Willow Grove ANG	141
Peterson AFB	473
Thule AB	17
Vandenberg AFB	327
Fresno-Yosemite ANG	74
Moffett Field ANG	73
Channel Islands ANG	80
USAF Academy	71
Wright-Patterson AFB	991
Springfield ANG	92
Rome Lab/Griffiss AFB	32
Rickenbacker ANG	111
Mansfield-Lahm ANG	79
Hancock Field ANG	74
Youngstown	179
Dobbins AFB	279
CPSG	58
Kelly ANG	65
Ellington Field	75
Brooks City Base	70
TOTAL	4207

Phase 2

Demand Location	End-Users
Scott AFB	1070
Springfield IL ANG	80
Fort Wayne ANG	69
Grissom ARB	101
Toledo ANG	69
Langley AFB	1355
Byrd Field ANG	75
Lambert Field	83
Minot AFB	407
Hickam AFB	539
Lajes Field AB	199
Randolph AFB	337
Lackland AFB	954
Fort Rucker	1
TOTAL	5339

Phase 3

Demand Location	End-Users
Dover AFB	473
New Castle ARB	77
Westover ARB	274
Stewart ANG	115
Fairchild AFB	288
March ARB	456
Reno-Tahoe ANG	78
Holloman AFB	617
Aviano AB	441
Akrotiri	2
Sembach AB	49
Elmendorf AFB	472
Anchorage ANG	77
Malmstorm AFB	516
Great Falls ANG	76
Kirtland AFB	347
Luke AFB	428
Sky Harbor ANG	73
Goodfellow AFB	70
Maxwell AFB	315
Birmingham ANG	73
Dannelly Field ANG	82
Key Field ANG	82
TOTAL	5481

Phase 4

Demand Location	End-Users
Andrews AFB	489
Baltimore ANG	138
Pentagon	208
Bolling AFB	256
Charlotte ANG	81
Seymour Johnson AFB	421
New Orleans NAS JRB	69
Burlington ANG	76
Francis S Gabreski ANGB	78
Stratton ANGB	82
Christchurch	1
Niagara Falls ANG	242
Bangor ANG	79
Pease ANG	81
FE Warren AFB	395
Cheyenne ANG	83
Buckley ANG	196
Eglin AFB	1149
Arnold AFB	5
Hurlburt Field AFB	516
Andersen AFB	130
Utapao IAP	1
Diego Garcia	9
Eielson AFB	349
TOTAL	5134

Phase 5

Demand Location	End-Users
McGuire AFB	653
Atlantic City ANG	76
Quonset ANG	80
Harrisburg ANG	86
McConnell AFB	319
Forbes Field ANG	79
Davis Monthan AFB	615
Soto Cano AB	13
Curacao AB	50
Manta AB	52
Tucson ANG	113
Mountain Home AFB	370
Boise ANG	79
Whiteman AFB	450
St Joseph ANG	82
Minneapolis-St Paul ANG	173
Minneapolis/St. Paul ARS	76
Keesler AFB	338
Gulfport ANG	43
Patrick AFB	151
Tyndall AFB	141
Edwards AFB	169
Spangdahlem AB	534
Kunsan AB	243
TOTAL	4985

Phase 6

Demand Location	End-Users
Charleston AFB	511
McEntire ANGB	85
Savannah ANG	90
Grand Forks AFB	219
Hector Field ANG	73
Duluth ANG	76
Pittsburgh IAP	233
Little Rock AFB	413
Memphis ANG	93
Greater Peoria ANG	104
Will Rogers ANG	89
Columbus AFB	179
Hulman Field ANG	69
Dyess AFB	428
Carswell ARS*	153
Sheppard AFB	153
Tulsa ANG	80
Hill AFB	475
Salt Lake City ANG	88
McClellan AFB	6
Ramstein AB	1253
Moron AB	115
Kadena AB	902
Los Angeles AFB	130
TOTAL	6017

Phase 7

Demand Location	End-Users
McChord AFB	489
Portland ANG	120
Kingsley Field ANG	67
Pope AFB	390
McGhee Tyson	85
Yeager	72
Moody AFB	348
Jacksonville ANG	74
Truax Field ANG	69
Volk Field ANG	34
Battle Creek/W K Kellogg	70
Alpena	27
Offutt AFB	251
Lincoln ANG	74
Des Moines ANG	22
Altus AFB	273
Nashville ANG	81
Martinsburg ANG	80
Yokota AB	455
Misawa AB	345
Incirlik AB	217
Izmir AB	26
Vance AFB	50
Robins AFB	487
Shaw AFB	410
Al Udeid AB	18
TOTAL	4634

Phase 8

Demand Location	End-Users
Travis AFB	618
Nellis AFB	611
Creech AFB	114
Beale AFB	533
Laughlin AFB	99
Tinker AFB	344
Cannon AFB	355
Selfridge ANG	221
Standiford Field	75
Bradley Field ANG	9
Bradley Field CIRF	9
Barnes ANG	70
Otis ANG	100
RAF Lakenheath	335
RAF Menwith Hill	20
RAF Fairford	45
RAF Mildenhall	378
Osan AB	480
Suwon AB	8
Kimhae AB	4
Taegu AB	12
Kwangju AB	8
TOTAL	4448

Appendix C: Pilot/IOT&E Model Output

10% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	4,5,6,8	91	5,6,8	93	1	5,8	100	9	8	111	19
20%	4,5,6,8	180	5,6,8	182	3	5,8	197	17	8	217	37
30%	4,5,6,8	269	5,6,8	272	4	5,8	293	25	8	323	55
40%	4,5,6,8	357	5,6,8	362	5	5,8	391	35	8	429	73
50%	4,5,6,8	453	5,6,8	460	6	5,8	498	45	8	537	84
60%	4,5,6,8	551	5,6,8	559	8	6,8	598	47	8	644	93
70%	4,5,6,8	649	5,6,8	658	9	6,8	697	48	8	750	101
80%	4,5,6,8	747	5,6,8	757	10	6,8	796	49	8	857	110
90%	4,5,6,8	845	5,6,8	856	11	6,8	895	51	8	963	118

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

20% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	4,5,6,8	91	5,6,8	93	1	5,8	100	9	8	111	19
20%	4,5,6,8	180	5,6,8	182	3	5,8	197	17	8	217	37
30%	4,5,6,8	269	5,6,8	272	4	5,8	293	25	8	323	55
40%	4,5,6,8	357	5,6,8	362	5	5,8	389	33	8	429	73
50%	4,5,6,8	446	5,6,8	453	6	5,8	487	41	8	537	91
60%	4,5,6,8	535	5,6,8	543	8	5,8	584	49	8	644	109
70%	4,5,6,8	623	5,6,8	632	9	5,8	680	57	8	750	127
80%	4,5,6,8	712	5,6,8	722	10	5,8	781	68	8	857	144
90%	4,5,6,8	805	5,6,8	816	11	5,8	884	79	8	963	158

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

30% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	4,5,6,8	91	5,6,8	93	1	5,8	100	9	8	111	19
20%	4,5,6,8	180	5,6,8	182	3	5,8	197	17	8	217	37
30%	4,5,6,8	269	5,6,8	272	4	5,8	293	25	8	323	55
40%	4,5,6,8	357	5,6,8	362	5	5,8	389	33	8	429	73
50%	4,5,6,8	446	5,6,8	453	6	5,8	487	41	8	537	91
60%	4,5,6,8	535	5,6,8	543	8	5,8	584	49	8	644	109
70%	4,5,6,8	623	5,6,8	632	9	5,8	680	57	8	750	127
80%	4,5,6,8	712	5,6,8	722	10	5,8	777	64	8	857	144
90%	4,5,6,8	801	5,6,8	812	11	5,8	873	72	8	963	162

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

40-100% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	4,5,6,8	91	5,6,8	93	1	5,8	100	9	8	111	19
20%	4,5,6,8	180	5,6,8	182	3	5,8	197	17	8	217	37
30%	4,5,6,8	269	5,6,8	272	4	5,8	293	25	8	323	55
40%	4,5,6,8	357	5,6,8	362	5	5,8	389	33	8	429	73
50%	4,5,6,8	446	5,6,8	453	6	5,8	487	41	8	537	91
60%	4,5,6,8	535	5,6,8	543	8	5,8	584	49	8	644	109
70%	4,5,6,8	623	5,6,8	632	9	5,8	680	57	8	750	127
80%	4,5,6,8	712	5,6,8	722	10	5,8	777	64	8	857	144
90%	4,5,6,8	801	5,6,8	812	11	5,8	873	72	8	963	162

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

Appendix D: Phase 1 Model Output

10% Training Capacity

Training	Optimal		7 Location Max			6 Location Max			5 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	5,7,8	409	5,7,8	409	0	5,7,8	409	0	5,7,8	409	0
20%	5,7,8	803	5,7,8	803	0	5,7,8	803	0	5,7,8	803	0
30%	4,5,6,7,8	1,210	4,5,6,7,8	1,210	0	4,5,6,7,8	1,210	0	4,5,6,7,8	1,210	0
40%	4,5,6,7,8	1,671	4,5,6,7,8	1,671	0	4,5,6,7,8	1,671	0	4,5,6,7,8	1,671	0
50%	1,2,4,5,6,7,8	2,170	1,2,4,5,6,7,8	2,170	0	1,2,5,6,7,8	2,175	5	3,5,6,7,8	2,259	90
60%	1,2,3,4,5,6,7,8	2,754	1,2,3,5,6,7,8	2,781	27	Infeasible	n/a	n/a	Infeasible	n/a	n/a
70%	1,2,3,4,5,6,7,8	3,157	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
80%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
90%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

4 Location Max			3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,7,8	409	0	5,7,8	409	0	5,8	409	0	8	416	7
5,7,8	803	0	5,7,8	803	0	5,8	804	0	8	818	15
5,6,7,8	1,210	0	5,7,8	1,213	4	7,8	1,256	46	Infeasible	n/a	n/a
5,6,7,8	1,672	1	3,7,8	1,854	183	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

20% Training Capacity

Training	Optimal		5 Location Max			4 Location Max			3 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	5,7,8	409	5,7,8	409	0	5,7,8	409	0	5,7,8	409	0
20%	5,7,8	803	5,7,8	803	0	5,7,8	803	0	5,7,8	803	0
30%	5,7,8	1,198	5,7,8	1,198	0	5,7,8	1,198	0	5,7,8	1,198	0
40%	5,7,8	1,595	5,7,8	1,595	0	5,7,8	1,595	0	5,7,8	1,595	0
50%	5,7,8	1,992	5,7,8	1,992	0	5,7,8	1,992	0	5,7,8	1,992	0
60%	4,5,6,7,8	2,407	4,5,6,7,8	2,407	0	5,6,7,8	2,408	1	5,7,8	2,414	7
70%	4,5,6,7,8	2,862	4,5,6,7,8	2,862	0	5,6,7,8	2,863	1	5,7,8	2,885	24
80%	4,5,6,7,8	3,327	4,5,6,7,8	3,327	0	5,6,7,8	3,329	1	3,7,8	3,687	360
90%	2,4,5,6,7,8	3,810	2,5,6,7,8	3,816	6	3,6,7,8	4,062	252	Infeasible	n/a	n/a

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,8	409.177	0	8	416	7
5,8	803.782	0	8	818	15
5,8	1198.683	1	8	1,220	21
5,8	1595.724	1	8	1,624	29
5,8	1993.686	2	Infeasible	n/a	n/a
7,8	2497.936	91	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a

*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

30% Training Capacity										
Training	Optimal		4 Location Max			3 Location Max			2 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	5,7,8	409	5,7,8	409	0	5,7,8	409	0	5,8	409	0
20%	5,7,8	803	5,7,8	803	0	5,7,8	803	0	5,8	804	0
30%	5,7,8	1,198	5,7,8	1,198	0	5,7,8	1,198	0	5,8	1,199	1
40%	5,7,8	1,595	5,7,8	1,595	0	5,7,8	1,595	0	5,8	1,596	1
50%	5,7,8	1,992	5,7,8	1,992	0	5,7,8	1,992	0	5,8	1,992	1
60%	5,7,8	2,385	5,7,8	2,385	0	5,7,8	2,385	0	5,8	2,386	1
70%	5,7,8	2,780	5,7,8	2,780	0	5,7,8	2,780	0	5,8	2,781	1
80%	4,5,6,7,8	3,179	5,6,7,8	3,179	0	5,7,8	3,182	3	7,8	3,267	88
90%	4,5,6,7,8	3,601	5,6,7,8	3,603	1	5,7,8	3,612	11	7,8	3,737	136

1 Location Max		
Locations*	Cost ($000)	Δ ($000)
8	416	7
8	818	15
8	1,220	21
8	1,624	29
8	2,027	36
8	2,428	43
Infeasible	n/a	n/a
Infeasible	n/a	n/a
Infeasible	n/a	n/a

*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

40% Training Capacity								
Training	Optimal		2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	5,7,8	$409	5,8	$409	$0	8	$416	$7
20%	5,7,8	$803	5,8	$804	$0	8	$818	$15
30%	5,7,8	$1,198	5,8	$1,199	$1	8	$1,220	$21
40%	5,7,8	$1,595	5,8	$1,596	$1	8	$1,624	$29
50%	5,7,8	$1,992	5,8	$1,992	$1	8	$2,027	$36
60%	5,7,8	$2,385	5,8	$2,386	$1	8	$2,428	$43
70%	5,7,8	$2,780	5,8	$2,781	$1	8	$2,830	$50
80%	5,7,8	$3,177	5,8	$3,178	$1	8	$3,234	$57
90%	5,7,8	$3,569	5,8	$3,571	$1	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

50-100% Training Capacity								
Training	Optimal		2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	5,7,8	$409	5,8	$409	$0	8	$416	$7
20%	5,7,8	$803	5,8	$804	$0	8	$818	$15
30%	5,7,8	$1,198	5,8	$1,199	$1	8	$1,220	$21
40%	5,7,8	$1,595	5,8	$1,596	$1	8	$1,624	$29
50%	5,7,8	$1,992	5,8	$1,992	$1	8	$2,027	$36
60%	5,7,8	$2,385	5,8	$2,386	$1	8	$2,428	$43
70%	5,7,8	$2,780	5,8	$2,781	$1	8	$2,830	$50
80%	5,7,8	$3,177	5,8	$3,178	$1	8	$3,234	$57
90%	5,7,8	$3,569	5,8	$3,571	$1	8	$3,633	$64

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

Appendix E: Phase 2 Model Output

10% Training Capacity

Training Demand	Optimal Locations*	Optimal Cost ($000)	6 Location Max Locations*	6 Location Max Cost ($000)	6 Location Max Δ ($000)	5 Location Max Locations*	5 Location Max Cost ($000)	5 Location Max Δ ($000)	4 Location Max Locations*	4 Location Max Cost ($000)	4 Location Max Δ ($000)
10%	5,8	514	5,8	514	0	5,8	514	0	5,8	514	0
20%	5,8	1,023	5,8	1,023	0	5,8	1,023	0	5,8	1,023	0
30%	2,4,5,7,8	1,599	2,4,5,7,8	1,599	0	2,4,5,7,8	1,599	0	5,6,7,8	1,606	7
40%	1,2,4,5,6,7,8	2,277	1,2,5,6,7,8	2,286	9	1,3,6,7,8	2,419	141	Infeasible	n/a	n/a
50%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
60%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
70%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
80%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
90%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

Training Demand	3 Location Max Locations*	3 Location Max Cost ($000)	3 Location Max Δ ($000)	2 Location Max Locations*	2 Location Max Cost ($000)	2 Location Max Δ ($000)	1 Location Max Locations*	1 Location Max Cost ($000)	1 Location Max Δ ($000)
10%	5,8	514	0	5,8	514	0	8	542	28
20%	5,8	1,023	0	5,8	1,023	0	Infeasible	n/a	n/a
30%	6,7,8	1,666	68	Infeasible	n/a	n/a	Infeasible	n/a	n/a
40%	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
50%	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
60%	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
70%	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
80%	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
90%	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

20% Training Capacity

Training Demand	Optimal Locations*	Optimal Cost ($000)	7 Location Max Locations*	7 Location Max Cost ($000)	7 Location Max Δ ($000)	6 Location Max Locations*	6 Location Max Cost ($000)	6 Location Max Δ ($000)	5 Location Max Locations*	5 Location Max Cost ($000)	5 Location Max Δ ($000)
10%	5,8	514	5,8	514	0	5,8	514	0	5,8	514	0
20%	5,8	1,023	5,8	1,023	0	5,8	1,023	0	5,8	1,023	0
30%	5,8	1,530	5,8	1,530	0	5,8	1,530	0	5,8	1,530	0
40%	5,8	2,037	5,8	2,037	0	5,8	2,037	0	5,8	2,037	0
50%	5,7,8	2,600	5,7,8	2,600	0	5,7,8	2,600	0	5,7,8	2,600	0
60%	2,4,5,7,8	3,189	2,4,5,7,8	3,189	0	2,4,5,7,8	3,189	0	2,4,5,7,8	3,189	0
70%	1,2,4,5,6,7,8	3,853	1,2,4,5,6,7,8	3,853	0	2,4,5,6,7,8	3,853	0	2,5,6,7,8	3,869	16
80%	1,2,4,5,6,7,8	4,546	1,2,4,5,6,7,8	4,546	0	1,2,3,6,7,8	4,564	18	3,5,6,7,8	4,753	207
90%	1,2,3,4,5,6,7,8	5,292	1,2,3,5,6,7,8	5,347	55	1,2,3,6,7,8	5,555	263	Infeasible	n/a	n/a

Training Demand	4 Location Max Locations*	4 Location Max Cost ($000)	4 Location Max Δ ($000)	3 Location Max Locations*	3 Location Max Cost ($000)	3 Location Max Δ ($000)	2 Location Max Locations*	2 Location Max Cost ($000)	2 Location Max Δ ($000)	1 Location Max Locations*	1 Location Max Cost ($000)	1 Location Max Δ ($000)
10%	5,8	514	0	5,8	514	0	5,8	514	0	8	542	28
20%	5,8	1,023	0	5,8	1,023	0	5,8	1,023	0	8	1,078	55
30%	5,8	1,530	0	5,8	1,530	0	5,8	1,530	0	8	1,613	83
40%	5,8	2,037	0	5,8	2,037	0	5,8	2,037	0	infeasible	n/a	n/a
50%	5,7,8	2,600	0	5,7,8	2,600	0	7,8	2,745	145	infeasible	n/a	n/a
60%	4,5,7,8	3,191	3	6,7,8	3,324	135	Infeasible	n/a	n/a	infeasible	n/a	n/a
70%	1,6,7,8	4,014	161	Infeasible	n/a	n/a	Infeasible	n/a	n/a	infeasible	n/a	n/a
80%	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	infeasible	n/a	n/a
90%	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	infeasible	n/a	n/a

*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

30% Training Capacity											
Training	Optimal		4 Location Max			3 Location Max			2 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	5,8	514	5,8	514	0	5,8	514	0	5,8	514	0
20%	5,8	1,023	5,8	1,023	0	5,8	1,023	0	5,8	1,023	0
30%	5,8	1,530	5,8	1,530	0	5,8	1,530	0	5,8	1,530	0
40%	5,8	2,037	5,8	2,037	0	5,8	2,037	0	5,8	2,037	0
50%	5,8	2,545	5,8	2,545	0	5,8	2,545	0	5,8	2,545	0
60%	5,7,8	3,054	5,7,8	3,054	0	5,7,8	3,054	0	5,8	3,054	0
70%	5,7,8	3,612	5,7,8	3,612	0	5,7,8	3,612	0	7,8	3,814	202
80%	5,7,8	4,180	5,7,8	4,180	0	5,7,8	4,180	0	Infeasible	n/a	n/a
90%	2,4,5,7,8	4,776	4,5,7,8	4,780	4	6,7,8	4,979	202	Infeasible	n/a	n/a

1 Location Max		
Locations*	Cost ($000)	Δ ($000)
800%	541,647	28
800%	1,077,609	55
800%	1,612,836	83
800%	2,147,109	110
800%	2,682,336	138
Infeasible	n/a	n/a
Infeasible	n/a	n/a
Infeasible	n/a	n/a
Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

40% Training Capacity								
Training	Optimal		2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	5,8	514	5,8	514	0	8	542	28
20%	5,8	1,023	5,8	1,023	0	8	1,078	55
30%	5,8	1,530	5,8	1,530	0	8	1,613	83
40%	5,8	2,037	5,8	2,037	0	8	2,147	110
50%	5,8	2,545	5,8	2,545	0	8	2,682	138
60%	5,8	3,053	5,8	3,053	0	8	3,218	165
70%	5,8	3,558	5,8	3,558	0	Infeasible	n/a	n/a
80%	5,8	4,068	5,8	4,068	0	Infeasible	n/a	n/a
90%	5,7,8	4,626	7,8	4,888	261	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

50% Training Capacity					
Training	Optimal		1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)
10%	5,8	514	8	542	28
20%	5,8	1,023	8	1,078	55
30%	5,8	1,530	8	1,613	83
40%	5,8	2,037	8	2,147	110
50%	5,8	2,545	8	2,682	138
60%	5,8	3,053	8	3,218	165
70%	5,8	3,558	8	3,751	193
80%	5,8	4,067	8	4,288	220
90%	5,8	4,574	8	Infeasible	n/a

* Supply Locations: 5- Hill, 8- Robins

60-100% Training Capacity					
Training	Optimal		1 Location		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)
10%	5,8	514	8	542	28
20%	5,8	1,023	8	1,078	55
30%	5,8	1,530	8	1,613	83
40%	5,8	2,037	8	2,147	110
50%	5,8	2,545	8	2,682	138
60%	5,8	3,053	8	3,218	165
70%	5,8	3,558	8	3,751	193
80%	5,8	4,067	8	4,288	220
90%	5,8	4,574	8	4,822	248
* Supply Locations: 5- Hill, 8- Robins					

Appendix F: Phase 3 Model Output

10% Training Capacity											
Training	Optimal		7 Location Max			6 Location Max			5 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,6,7,8	581	1,6,7,8	581	0	1,6,7,8	581	0	1,6,7,8	581	0
20%	1,6,7,8	1,191	1,6,7,8	1,191	0	1,6,7,8	1,191	0	1,6,7,8	1,191	0
30%	1,4,5,6,7,8	1,835	1,4,5,6,7,8	1,835	0	1,4,5,6,7,8	1,835	0	1,4,5,7,8	1,837	2
40%	1,2,3,4,5,6,7,8	2,529	1,3,4,5,6,7,8	2,532	3	1,2,5,6,7,8	2,557	27	1,3,6,7,8	2,688	159
50%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
60%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
70%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
80%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
90%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
4 Location Max			3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
1,6,7,8	581	0	5,7,8	594	12	7,8	641	59	8	777	195
1,6,7,8	1,191	0	5,7,8	1,218	28	7,8	1,297	106	Infeasible	n/a	n/a
1,5,7,8	1,842	7	3,7,8	2,036	201	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

20% Training Capacity											
Training	Optimal		7 Location Max			6 Location Max			5 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,6,7,8	572	1,6,7,8	572	0	1,6,7,8	572	0	1,6,7,8	572	0
20%	1,5,7,8	1,153	1,5,7,8	1,153	0	1,5,7,8	1,153	0	1,5,7,8	1,153	0
30%	1,5,7,8	1,750	1,5,7,8	1,750	0	1,5,7,8	1,750	0	1,5,7,8	1,750	0
40%	1,5,7,8	2,365	1,5,7,8	2,365	0	1,5,7,8	2,365	0	1,5,7,8	2,365	0
50%	1,4,5,7,8	3,008	1,4,5,7,8	3,008	0	1,4,5,7,8	3,008	0	1,4,5,7,8	3,008	0
60%	1,4,5,6,7,8	3,658	1,4,5,6,7,8	3,658	0	1,4,5,6,7,8	3,658	0	1,4,5,7,8	3,662	4
70%	1,3,4,5,6,7,8	4,325	1,3,4,5,6,7,8	4,325	0	1,4,5,6,7,8	4,325	0	1,5,6,7,8	4,350	25
80%	1,2,3,4,5,6,7,8	5,039	1,3,4,5,6,7,8	5,043	5	1,2,5,6,7,8	5,095	56	1,3,6,7,8	5,355	316
90%	1,2,3,4,5,6,7,8	5,819	1,2,3,5,6,7,8	5,877	58	Infeasible	n/a	n/a	Infeasible	n/a	n/a
4 Location Max			3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
1,6,7,8	572	0	5,7,8	582	10	7,8	641	69	7	741	169
1,5,7,8	1,153	0	5,7,8	1,177	24	7,8	1,271	118	8	1,541	389
1,5,7,8	1,750	0	5,7,8	1,785	36	7,8	1,901	152	8	2,301	551
1,5,7,8	2,365	0	5,7,8	2,419	54	7,8	2,576	211	Infeasible	n/a	n/a
1,5,7,8	3,014	5	5,7,8	3,098	89	Infeasible	n/a	n/a	Infeasible	n/a	n/a
1,5,7,8	3,672	14	6,7,8	3,910	252	Infeasible	n/a	n/a	Infeasible	n/a	n/a
1,3,7,8	4,657	332	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

30% Training Capacity											
Training	Optimal		5 Location Max			4 Location Max			3 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,7,8	572	1,6,7,8	572	0	1,6,7,8	572	0	5,7,8	582	10
20%	1,5,7,8	1,133	1,5,7,8	1,137	4	1,5,7,8	1,137	4	5,7,8	1,161	27
30%	1,5,7,8	1,702	1,5,7,8	1,720	18	1,5,7,8	1,720	18	5,7,8	1,756	54
40%	1,5,7,8	2,314	1,5,7,8	2,314	0	1,5,7,8	2,314	0	5,7,8	2,361	47
50%	1,5,7,8	2,932	1,5,7,8	2,931,740	n/a	1,5,7,8	2,932	0	5,7,8	2,991	60
60%	1,5,7,8	3,541	1,5,7,8	3,540,985	n/a	1,5,7,8	3,541	0	5,7,8	3,622	81
70%	1,4,5,7,8	4,174	1,4,5,7,8	4,173,807	n/a	1,5,7,8	4,179	5	5,7,8	4,291	118
80%	1,4,5,6,7,8	4,823	1,4,5,7,8	4,823,861	n/a	1,5,7,8	4,832	9	5,7,8	4,972	149
90%	1,4,5,6,7,8	5,479	1,4,5,7,8	5,484,615	n/a	1,5,7,8	5,499	20	6,7,8	5,856	376

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
7,8	641	69	7	741	169
7,8	1,271	137	7	1,468	335
7,8	1,896	194	8	2,301	599
7,8	2,524	210	8	3,063	749
7,8	3,187	255	8	3,831	900
7,8	3,858	317	Infeasible	n/a	n/a
7,8	4,559	386	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

40% Training Capacity											
Training	Optimal		4 Location Max			3 Location Max			2 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,7,8	572	1,5,7,8	572	0	5,7,8	582	10	7,8	641	69
20%	1,5,7,8	1,133	1,5,7,8	1,133	0	5,7,8	1,153	20	7,8	1,271	137
30%	1,5,7,8	1,702	1,5,7,8	1,702	0	5,7,8	1,738	36	7,8	1,896	194
40%	1,5,7,8	2,290	1,5,7,8	2,290	0	5,7,8	2,337	47	7,8	2,524	235
50%	1,5,7,8	2,886	1,5,7,8	2,886	0	5,7,8	2,945	60	7,8	3,158	272
60%	1,5,7,8	3,488	1,5,7,8	3,488	0	5,7,8	3,560	71	7,8	3,791	303
70%	1,5,7,8	4,102	1,5,7,8	4,102	0	5,7,8	4,185	83	7,8	4,459	357
80%	1,5,7,8	4,715	1,5,7,8	4,715	0	5,7,8	4,822	107	7,8	5,136	421
90%	1,4,5,7,8	5,346	1,5,7,8	5,350	4	5,7,8	5,492	146	7,8	5,839	493

1 Location Max		
Locations*	Cost ($000)	Δ ($000)
7	741	169
7	1,468	335
7	2,190	488
8	3,063	773
8	3,831	946
8	4,588	1,099
Infeasible	n/a	n/a
Infeasible	n/a	n/a
Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

50% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,7,8	572	5,7,8	582	10	7,8	641	69	7	741	169
20%	1,5,7,8	1,133	5,7,8	1,153	20	7,8	1,271	137	7	1,468	335
30%	1,5,7,8	1,693	5,7,8	1,727	33	7,8	1,896	203	7	2,190	496
40%	1,5,7,8	2,269	5,7,8	2,317	47	7,8	2,524	255	8	3,063	793
50%	1,5,7,8	2,864	5,7,8	2,924	60	7,8	3,158	294	8	3,831	967
60%	1,5,7,8	3,450	5,7,8	3,521	71	7,8	3,781	330	8	4,588	1,138
70%	1,5,7,8	4,049	5,7,8	4,132	83	7,8	4,407	358	8	5,348	1,299
80%	1,5,7,8	4,662	5,7,8	4,757	95	7,8	5,067	405	8	6,109	1,447
90%	1,5,7,8	5,277	5,7,8	5,384	106	7,8	5,738	460	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

60% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,7,8	572	5,7,8	582	10	7,8	641	69	7	741	169
20%	1,5,7,8	1,133	5,7,8	1,153	20	7,8	1,271	137	7	1,468	335
30%	1,5,7,8	1,691	5,7,8	1,720	29	7,8	1,896	205	7	2,190	498
40%	1,5,7,8	2,259	5,7,8	2,305	46	7,8	2,524	265	7	2,915	656
50%	1,5,7,8	2,843	5,7,8	2,903	60	7,8	3,158	315	8	3,831	988
60%	1,5,7,8	3,429	5,7,8	3,500	71	7,8	3,781	352	8	4,588	1,159
70%	1,5,7,8	4,018	5,7,8	4,101	83	7,8	4,407	389	8	5,348	1,330
80%	1,5,7,8	4,613	5,7,8	4,708	95	7,8	5,034	421	8	6,109	1,496
90%	1,5,7,8	5,225	5,7,8	5,331	106	7,8	5,678	453	8	6,872	1,647

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

70% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,7,8	572	5,7,8	582	10	7,8	641	69	7	741	169
20%	1,5,7,8	1,133	5,7,8	1,153	20	7,8	1,271	137	7	1,468	335
30%	1,5,7,8	1,691	5,7,8	1,720	29	7,8	1,896	205	7	2,190	498
40%	1,5,7,8	2,252	5,7,8	2,296	44	7,8	2,524	272	7	2,915	664
50%	1,5,7,8	2,830	5,7,8	2,890	60	7,8	3,158	328	7	3,647	817
60%	1,5,7,8	3,408	5,7,8	3,479	71	7,8	3,781	373	8	4,588	1,180
70%	1,5,7,8	3,997	5,7,8	4,080	83	7,8	4,407	410	8	5,348	1,351
80%	1,5,7,8	4,587	5,7,8	4,682	95	7,8	5,034	447	8	6,109	1,522
90%	1,5,7,8	5,180	5,7,8	5,286	106	7,8	5,662	482	8	6,872	1,692

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

80% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,7,8	572	5,7,8	582	10	7,8	641	69	7	741	169
20%	1,5,7,8	1,133	5,7,8	1,153	20	7,8	1,271	137	7	1,468	335
30%	1,5,7,8	1,691	5,7,8	1,720	29	7,8	1,896	205	7	2,190	498
40%	1,5,7,8	2,252	5,7,8	2,290	38	7,8	2,524	272	7	2,915	664
50%	1,5,7,8	2,822	5,7,8	2,878	56	7,8	3,158	336	7	3,647	825
60%	1,5,7,8	3,372	5,7,8	3,464	92	7,8	3,781	409	7	4,366	995
70%	1,5,7,8	3,976	5,7,8	4,059	83	7,8	4,407	431	8	5,348	1,372
80%	1,5,7,8	4,566	5,7,8	4,660	95	7,8	5,034	468	8	6,109	1,543
90%	1,5,7,8	5,157	5,7,8	5,263	106	7,8	5,662	506	8	6,872	1,715

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

90% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,7,8	572	5,7,8	582	10	7,8	641	69	7	741	169
20%	1,5,7,8	1,133	5,7,8	1,153	20	7,8	1,271	137	7	1,468	335
30%	1,5,7,8	1,691	5,7,8	1,720	29	7,8	1,896	205	7	2,190	498
40%	1,5,7,8	2,251	5,7,8	2,290	39	7,8	2,524	273	7	2,915	664
50%	1,5,7,8	2,816	5,7,8	2,871	55	7,8	3,158	342	7	3,647	831
60%	1,5,7,8	3,383	5,7,8	3,453	69	7,8	3,781	397	7	4,366	983
70%	1,5,7,8	3,959	5,7,8	4,042	83	7,8	4,407	448	8	5,348	1,389
80%	1,5,7,8	4,545	5,7,8	4,639	95	7,8	5,034	489	8	6,109	1,564
90%	1,5,7,8	5,136	5,7,8	5,242	106	7,8	5,662	527	8	6,872	1,736

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

100% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,7,8	572	5,7,8	582	10	7,8	641	69	7	741	169
20%	1,5,7,8	1,133	5,7,8	1,153	20	7,8	1,271	137	7	1,468	335
30%	1,5,7,8	1,691	5,7,8	1,720	29	7,8	1,896	205	7	2,190	498
40%	1,5,7,8	2,251	5,7,8	2,290	39	7,8	2,524	273	7	2,915	664
50%	1,5,7,8	2,816	5,7,8	2,865	49	7,8	3,158	342	7	3,647	831
60%	1,5,7,8	3,376	5,7,8	3,443	67	7,8	3,781	405	7	4,366	991
70%	1,5,7,8	3,947	5,7,8	4,030	83	7,8	4,407	460	8	5,348	1,401
80%	1,5,7,8	4,526	5,7,8	4,620	95	7,8	5,034	508	8	6,109	1,583
90%	1,5,7,8	5,114	5,7,8	5,221	106	7,8	5,662	548	8	6,872	1,758
* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

Appendix G: Phase 4 Model Output

10% Training Capacity

Training	Optimal		7 Location Max			6 Location Max			5 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,6,8	488	1,5,6,8	488	0	1,5,6,8	488	0	1,5,6,8	488	0
20%	1,5,6,8	966	1,5,6,8	966	0	1,5,6,8	966	0	1,5,6,8	966	0
30%	1,4,5,6,7,8	1,472	1,4,5,6,7,8	1,472	0	1,4,5,6,7,8	1,472	0	1,4,5,6,8	1,476	5
40%	1,2,4,5,6,7,8	2,053	1,2,4,5,6,7,8	2,053	0	1,4,5,6,7,8	2,054	1	1,3,6,7,8	2,184	131
50%	1,2,3,4,5,6,7,8	2,762	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
60%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
70%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
80%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
90%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

4 Location Max			3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
1,5,6,8	488	0	5,6,8	488	0	5,8	493	4	8	506	18
1,5,6,8	966	0	5,6,8	966	0	5,8	974	8	Infeasible	n/a	n/a
1,5,6,8	1,491	19	1,7,8	1,555	83	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

20% Training Capacity

Training	Optimal		7 Location Max			6 Location Max			5 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,6,8	488	1,5,6,8	488	0	1,5,6,8	488	0	1,5,6,8	488	0
20%	1,5,6,8	966	1,5,6,8	966	0	1,5,6,8	966	0	1,5,6,8	966	0
30%	1,5,6,8	1,438	1,5,6,8	1,438	0	1,5,6,8	1,438	0	1,5,6,8	1,438	0
40%	1,5,6,8	1,917	1,5,6,8	1,917	0	1,5,6,8	1,917	0	1,5,6,8	1,917	0
50%	1,5,6,8	2,406	1,5,6,8	2,406	0	1,5,6,8	2,406	0	1,5,6,8	2,406	0
60%	1,4,5,6,7,8	2,930	1,4,5,6,7,8	2,930	0	1,4,5,6,7,8	2,930	0	1,4,5,6,8	2,937	7
70%	1,4,5,6,7,8	3,499	1,4,5,6,7,8	3,499	0	1,4,5,6,7,8	3,499	0	1,5,6,7,8	3,516	17
80%	1,2,4,5,6,7,8	4,082	1,2,4,5,6,7,8	4,082	0	1,4,5,6,7,8	4,084	2	1,2,6,7,8	4,238	156
90%	1,2,3,4,5,6,7,8	4,702	1,2,3,5,6,7,8	4,785	84	1,3,5,6,7,8	4,914	212	Infeasible	n/a	n/a

4 Location Max			3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
1,5,6,8	488	0	5,6,8	488	0	5,8	493	4	8	506	18
1,5,6,8	966	0	5,6,8	966	0	5,8	974	8	8	1,001	36
1,5,6,8	1,438	0	5,6,8	1,438	0	5,8	1,450	12	8	1,490	53
1,5,6,8	1,917	0	5,6,8	1,917	1	5,8	1,933	16	Infeasible	n/a	n/a
1,5,6,8	2,406	0	1,5,8	2,428	22	5,8	2,597	191	Infeasible	n/a	n/a
1,5,6,8	2,968	38	1,7,8	3,096	167	Infeasible	n/a	n/a	Infeasible	n/a	n/a
1,6,7,8	3,633	133	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

30% Training Capacity												
Training	Optimal		5 Location Max			4 Location Max			3 Location Max			
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	
10%	1,5,6,8	488	1,5,6,8	488	0	1,5,6,8	488	0	5,6,8	488	0	
20%	1,5,6,8	966	1,5,6,8	966	0	1,5,6,8	966	0	5,6,8	966	0	
30%	1,5,6,8	1,438	1,5,6,8	1,438	0	1,5,6,8	1,438	0	5,6,8	1,438	0	
40%	1,5,6,8	1,916	1,5,6,8	1,916	0	1,5,6,8	1,916	0	5,6,8	1,916	1	
50%	1,5,6,8	2,393	1,5,6,8	2,393	0	1,5,6,8	2,393	0	5,6,8	2,394	1	
60%	1,5,6,8	2,866	1,5,6,8	2,866	0	1,5,6,8	2,866	0	5,6,8	2,867	1	
70%	1,5,6,8	3,352	1,5,6,8	3,352	0	1,5,6,8	3,352	0	1,5,8	3,380	28	
80%	1,4,5,6,8	3,849	1,4,5,6,8	3,849	0	1,5,6,8	3,849	0	5,7,8	4,016	167	
90%	1,4,5,6,7,8	4,387	1,4,5,6,8	4,397	11	1,5,6,8	4,443	56	1,7,8	4,636	249	

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,8	493	4	8	506	18
5,8	974	8	8	1,001	36
5,8	1,450	12	8	1,490	53
5,8	1,932	16	8	1,986	70
5,8	2,414	21	8	2,481	88
5,8	2,891	25	Infeasible	n/a	n/a
6,8	3,583	232	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

40% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,6,8	488	5,6,8	488	0	5,8	493	4	8	506	18
20%	1,5,6,8	966	5,6,8	966	0	5,8	974	8	8	1,001	36
30%	1,5,6,8	1,438	5,6,8	1,438	0	5,8	1,450	12	8	1,490	53
40%	1,5,6,8	1,916	5,6,8	1,916	1	5,8	1,932	16	8	1,986	70
50%	1,5,6,8	2,393	5,6,8	2,394	1	5,8	2,414	21	8	2,481	88
60%	1,5,6,8	2,865	5,6,8	2,866	1	5,8	2,890	25	8	2,970	105
70%	1,5,6,8	3,341	5,6,8	3,342	1	5,8	3,370	29	8	3,463	122
80%	1,5,6,8	3,817	5,6,8	3,818	1	5,8	3,850	33	Infeasible	n/a	n/a
90%	1,5,6,8	4,299	5,6,8	4,319	20	1,8	4,455	156	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

50-100% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,5,6,8	488	5,6,8	488	0	5,8	493	4	8	506	18
20%	1,5,6,8	966	5,6,8	966	0	5,8	974	8	8	1,001	36
30%	1,5,6,8	1,438	5,6,8	1,438	0	5,8	1,450	12	8	1,490	53
40%	1,5,6,8	1,916	5,6,8	1,916	1	5,8	1,932	16	8	1,986	70
50%	1,5,6,8	2,393	5,6,8	2,394	1	5,8	2,414	21	8	2,481	88
60%	1,5,6,8	2,865	5,6,8	2,866	1	5,8	2,890	25	8	2,970	105
70%	1,5,6,8	3,341	5,6,8	3,342	1	5,8	3,370	29	8	3,463	122
80%	1,5,6,9	3,815	5,6,8	3,816	1	5,8	3,848	33	8	3,955	140
90%	1,5,6,8	4,291	5,6,8	4,292	1	5,8	4,327	37	8	4,447	157

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

Appendix H: Phase 5 Model Output

10% Training Capacity											
Training	Optimal		7 Location Max			6 Location Max			5 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,2,4,5,6,8	482	1,2,4,5,6,8	482	0	1,2,4,5,6,8	482	0	1,4,5,6,8	483	1
20%	1,2,4,5,6,8	967	1,2,4,5,6,8	967	0	1,2,4,5,6,8	967	0	1,4,5,6,8	968	1
30%	1,2,4,5,6,7,8	1,461	1,2,4,5,6,7,8	1,461	0	1,4,5,6,7,8	1,465	3	1,5,6,7,7	1,472	10
40%	1,2,4,5,6,7,8	2,015	1,2,4,5,6,7,8	2,015	0	1,2,5,6,7,8	2,024	9	1,5,6,7,8	2,037	22
50%	1,2,3,4,5,6,7,8	2,673	1,2,3,5,6,7,8	2,699	26	Infeasible	n/a	n/a	Infeasible	n/a	n/a
60%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
70%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
80%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
90%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
4 Location Max			3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
1,5,6,8	485	3	1,5,8	502	19	1,8	543	61	8	590	108
1,5,6,8	973	6	1,6,8	1,001	34	1,8	1,068	101	Infeasible	n/a	n/a
1,6,7,8	1,503	41	1,7,8	1,607	146	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

20% Training Capacity											
Training	Optimal		6 Location Max			5 Location Max			4 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,2,4,5,6,8	479	1,2,4,5,6,8	479	0	1,4,5,6,8	479	1	1,5,6,8	482	3
20%	1,2,4,5,6,8	948	1,2,4,5,6,8	948	0	1,4,5,6,8	949	1	1,5,6,8	954	6
30%	1,2,4,5,6,8	1,430	1,2,4,5,6,8	1,430	0	1,4,5,6,8	1,431	2	1,5,6,8	1,438	9
40%	1,2,4,5,6,8	1,921	1,2,4,5,6,8	1,921	0	1,4,5,6,8	1,924	2	1,5,6,8	1,933	12
50%	1,2,4,5,6,8	2,409	1,2,4,5,6,8	2,409	0	1,4,5,6,8	2,412	3	1,5,6,8	2,423	15
60%	1,2,4,5,6,7,8	2,915	1,4,5,6,7,8	2,922	7	1,5,6,7,8	2,935	21	1,6,7,8	2,998	83
70%	1,2,4,5,6,7,8	3,435	1,4,5,6,7,8	3,444	9	1,5,6,7,8	3,460	25	1,6,7,8	3,571	136
80%	1,2,4,5,6,7,8	4,009	1,2,5,6,7,8	4,027	18	1,5,6,7,8	4,052	43	Infeasible	n/a	n/a
90%	1,2,4,5,6,7,8	4,618	1,3,5,6,7,8	4,756	138	Infeasible	n/a	n/a	Infeasible	n/a	n/a
3 Location Max			2 Location Max			1 Location Max					
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)			
1,5,8	494	16	1,8	543	65	8	590	111			
1,5,8	986	37	1,8	1,068	120	8	1,160	212			
1,5,8	1,486	56	1,8	1,591	161	8	1,728	299			
1,6,8	1,990	69	1,8	2,123	202	Infeasible	n/a	n/a			
1,5,8	2,541	132	7,8	2,899	490	Infeasible	n/a	n/a			
1,7,8	3,206	291	Infeasible	n/a	n/a	Infeasible	n/a	n/a			
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a			
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a			
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a			
* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

30% Training Capacity													
Training	Optimal		6 Location Max			5 Location Max			4 Location Max				
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)		
10%	1,2,4,5,6,8	479	1,2,4,5,6,8	479	0	1,4,5,6,8	479	1	1,5,6,8	482	3		
20%	1,2,4,5,6,8	941	1,2,4,5,6,8	941	0	1,4,5,6,8	942	1	1,5,6,8	947	6		
30%	1,2,4,5,6,8	1,411	1,2,4,5,6,8	1,411	0	1,4,5,6,8	1,413	2	1,5,6,8	1,420	9		
40%	1,2,4,5,6,8	1,902	1,2,4,5,6,8	1,902	0	1,4,5,6,8	1,904	2	1,5,6,8	1,913	12		
50%	1,2,4,5,6,8	2,389	1,2,4,5,6,8	2,389	0	1,4,5,6,8	2,392	3	1,5,6,8	2,404	15		
60%	1,2,4,5,6,8	2,871	1,2,4,5,6,8	2,871	0	1,4,5,6,8	2,875	4	1,5,6,8	2,889	17		
70%	1,2,4,5,6,8	3,362	1,2,4,5,6,8	3,362	0	1,4,5,6,8	3,366	4	1,5,6,8	3,382	20		
80%	1,2,4,5,6,7,8	3,854	1,4,5,6,7,8	3,863	9	1,5,6,7,8	3,881	27	1,4,5,8	3,912	58		
90%	1,2,4,5,6,7,8	4,364	1,4,5,6,7,8	4,375	10	1,5,6,7,8	4,395	31	1,6,7,8	4,489	124		

3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
1,5,8	494	16	1,8	543	65	8	590	111
1,5,8	972	31	1,8	1,068	127	8	1,160	219
1,5,8	1,467	56	1,8	1,591	179	8	1,728	317
1,5,8	1,977	75	1,8	2,123	222	8	2,307	406
1,5,8	2,483	94	1,8	2,651	262	8	2,881	492
1,6,8	2,974	103	1,8	3,173	302	Infeasible	n/a	n/a
1,5,8	3,502	140	6,8	3,922	560	Infeasible	n/a	n/a
1,6,8	4,126	272	7,8	4,634	780	Infeasible	n/a	n/a
1,7,8	4,800	436	Infeasible	n/a	n/a	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

40% Training Capacity											
Training	Optimal		5 Location Max			4 Location Max			3 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,2,4,5,6,8	479	1,4,5,6,8	479	1	1,5,6,8	482	3	1,5,8	494	16
20%	1,2,4,5,6,8	941	1,4,5,6,8	942	1	1,5,6,8	947	6	1,5,8	972	31
30%	1,2,4,5,6,8	1,401	1,4,5,6,8	1,403	2	1,5,6,8	1,409	9	1,5,8	1,449	48
40%	1,2,4,5,6,8	1,883	1,4,5,6,8	1,886	2	1,5,6,8	1,895	12	1,5,8	1,958	74
50%	1,2,4,5,6,8	2,370	1,4,5,6,8	2,373	3	1,5,6,8	2,385	15	1,5,8	2,463	93
60%	1,2,4,5,6,8	2,851	1,4,5,6,8	2,855	4	1,5,6,8	2,869	17	1,5,8	2,964	112
70%	1,2,4,5,6,8	3,342	1,4,5,6,8	3,346	4	1,5,6,8	3,362	20	1,6,8	3,472	130
80%	1,2,4,5,6,8	3,825	1,4,5,6,8	3,830	5	1,5,6,8	3,849	23	1,6,8	3,963	137
90%	1,2,4,5,6,8	4,310	1,4,5,6,8	4,315	5	1,5,6,8	4,336	26	1,4,8	4,481	171

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,8	541	62	8	590	111
5,8	1,064	123	8	1,160	219
5,8	1,586	185	8	1,728	327
1,8	2,123	240	8	2,307	424
1,8	2,651	281	8	2,881	510
1,8	3,173	322	8	3,447	595
1,8	3,705	363	8	4,025	683
1,8	4,228	403	Infeasible	n/a	n/a
1,8	4,818	508	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

50% Training Capacity													
Training	Optimal		5 Location Max			4 Location Max			3 Location Max				
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)		
10%	1,2,4,5,6,8	479	1,4,5,6,8	479	1	1,5,6,8	482	3	1,5,8	494	16		
20%	1,2,4,5,6,8	941	1,4,5,6,8	942	1	1,5,6,8	947	6	1,5,8	972	31		
30%	1,2,4,5,6,8	1,401	1,4,5,6,8	1,403	2	1,5,6,8	1,409	9	1,5,8	1,446	46		
40%	1,2,4,5,6,8	1,870	1,4,5,6,8	1,872	2	1,5,6,8	1,882	12	1,5,8	1,940	70		
50%	1,2,4,5,6,8	2,352	1,4,5,6,8	2,355	3	1,5,6,8	2,366	15	1,5,8	2,444	93		
60%	1,2,4,5,6,8	2,833	1,4,5,6,8	2,837	4	1,5,6,8	2,850	17	1,5,8	2,944	111		
70%	1,2,4,5,6,8	3,322	1,4,5,6,8	3,327	4	1,5,6,8	3,343	20	1,5,8	3,454	131		
80%	1,2,4,5,6,8	3,805	1,4,5,6,8	3,810	5	1,5,6,8	3,829	23	1,5,8	3,955	150		
90%	1,2,4,5,6,8	4,290	1,4,5,6,8	4,295	5	1,5,6,8	4,316	26	1,6,8	4,454	164		

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,8	541	62	8	590	111
5,8	1,064	123	8	1,160	219
5,8	1,584	183	8	1,728	327
1,8	2,123	253	8	2,307	437
1,8	2,651	299	8	2,881	529
1,8	3,173	340	8	3,447	614
1,8	3,705	382	8	4,025	703
1,8	4,228	423	8	4,594	788
1,8	4,752	462	8	5,163	874

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

60% Training Capacity											
Training	Optimal		5 Location Max			4 Location Max			3 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,2,4,5,6,8	479	1,4,5,6,8	479	1	1,5,6,8	482	3	1,5,8	494	16
20%	1,2,4,5,6,8	941	1,4,5,6,8	942	1	1,5,6,8	947	6	1,5,8	972	31
30%	1,2,4,5,6,8	1,401	1,4,5,6,8	1,403	2	1,5,6,8	1,409	9	1,5,8	1,446	46
40%	1,2,4,5,6,8	1,869	1,4,5,6,8	1,872	2	1,5,6,8	1,882	12	1,5,8	1,931	61
50%	1,2,4,5,6,8	2,336	1,4,5,6,8	2,339	3	1,5,6,8	2,350	15	1,5,8	2,426	90
60%	1,2,4,5,6,8	2,815	1,4,5,6,8	2,818	4	1,5,6,8	2,832	17	1,5,8	2,925	111
70%	1,2,4,5,6,8	3,304	1,4,5,6,8	3,308	4	1,5,6,8	3,325	20	1,5,8	3,434	130
80%	1,2,4,5,6,8	3,787	1,4,5,6,8	3,791	5	1,5,6,8	3,810	23	1,5,8	3,935	149
90%	1,2,4,5,6,8	4,270	1,4,5,6,8	4,275	5	1,5,6,8	4,296	26	1,6,8	4,438	169

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,8	541	62	8	590	111
5,8	1,064	123	8	1,160	219
5,8	1,584	183	8	1,728	327
5,8	2,115	245	8	2,307	438
1,8	2,651	315	8	2,881	545
1,8	3,173	358	8	3,447	632
1,8	3,705	401	8	4,025	721
1,8	4,228	442	8	4,594	807
1,8	4,752	482	8	5,163	894

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

70% Training Capacity											
Training	Optimal		5 Location Max			4 Location Max			3 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,2,4,5,6,8	479	1,4,5,6,8	479	1	1,5,6,8	482	3	1,5,8	494	16
20%	1,2,4,5,6,8	941	1,4,5,6,8	942	1	1,5,6,8	947	6	1,5,8	972	31
30%	1,2,4,5,6,8	1,401	1,4,5,6,8	1,403	2	1,5,6,8	1,409	9	1,5,8	1,446	46
40%	1,2,4,5,6,8	1,869	1,4,5,6,8	1,872	2	1,5,6,8	1,881	12	1,5,8	1,931	61
50%	1,2,4,5,6,8	2,334	1,4,5,6,8	2,338	3	1,5,6,8	2,349	15	1,5,8	2,413	78
60%	1,2,4,5,6,8	2,797	1,4,5,6,8	2,800	4	1,5,6,8	2,814	17	1,5,8	2,907	111
70%	1,2,4,5,6,8	3,286	1,4,5,6,8	3,290	4	1,5,6,8	3,306	20	1,5,8	3,416	130
80%	1,2,4,5,6,8	3,768	1,4,5,6,8	3,773	5	1,5,6,8	3,791	23	1,5,8	3,916	148
90%	1,2,4,5,6,8	4,251	1,4,5,6,8	4,257	5	1,5,6,8	4,277	26	1,5,8	4,418	167

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,8	541	62	8	590	111
5,8	1,064	123	8	1,160	219
5,8	1,584	183	8	1,728	327
5,8	2,115	245	8	2,307	438
5,8	2,642	307	8	2,881	546
1,8	3,173	377	8	3,447	650
1,8	3,705	419	8	4,025	739
1,8	4,228	460	8	4,594	825
1,8	4,752	501	8	5,163	912

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

80% Training Capacity											
Training	Optimal		5 Location Max			4 Location Max			3 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,2,4,5,6,8	479	1,4,5,6,8	479	1	1,5,6,8	482	3	1,5,8	494	16
20%	1,2,4,5,6,8	941	1,4,5,6,8	942	1	1,5,6,8	947	6	1,5,8	972	31
30%	1,2,4,5,6,8	1,401	1,4,5,6,8	1,403	2	1,5,6,8	1,409	9	1,5,8	1,446	46
40%	1,2,4,5,6,8	1,869	1,4,5,6,8	1,872	2	1,5,6,8	1,881	12	1,5,8	1,931	61
50%	1,2,4,5,6,8	2,334	1,4,5,6,8	2,338	3	1,5,6,8	2,349	15	1,5,8	2,411	76
60%	1,2,4,5,6,8	2,794	1,4,5,6,8	2,798	4	1,5,6,8	2,811	17	1,5,8	2,889	95
70%	1,2,4,5,6,8	3,268	1,4,5,6,8	3,272	4	1,5,6,8	3,288	20	1,5,8	3,397	130
80%	1,2,4,5,6,8	3,750	1,4,5,6,8	3,755	5	1,5,6,8	3,773	23	1,5,8	3,898	148
90%	1,2,4,5,6,8	4,233	1,4,5,6,8	4,238	5	1,5,6,8	4,259	26	1,5,8	4,399	166

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,8	541	62	8	590	111
5,8	1,064	123	8	1,160	219
5,8	1,584	183	8	1,728	327
5,8	2,115	245	8	2,307	438
5,8	2,642	307	8	2,881	546
5,8	3,163	369	8	3,447	653
1,8	3,705	437	8	4,025	757
1,8	4,228	478	8	4,594	844
1,8	4,752	519	8	5,163	930

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

90% Training Capacity											
Training	Optimal		5 Location Max			4 Location Max			3 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,2,4,5,6,8	479	1,4,5,6,8	479	1	1,5,6,8	482	3	1,5,8	494	16
20%	1,2,4,5,6,8	941	1,4,5,6,8	942	1	1,5,6,8	947	6	1,5,8	972	31
30%	1,2,4,5,6,8	1,401	1,4,5,6,8	1,403	2	1,5,6,8	1,409	9	1,5,8	1,446	46
40%	1,2,4,5,6,8	1,869	1,4,5,6,8	1,872	2	1,5,6,8	1,881	12	1,5,8	1,931	61
50%	1,2,4,5,6,8	2,334	1,4,5,6,8	2,338	3	1,5,6,8	2,349	15	1,5,8	2,411	76
60%	1,2,4,5,6,8	2,794	1,4,5,6,8	2,798	4	1,5,6,8	2,811	17	1,5,8	2,885	91
70%	1,2,4,5,6,8	3,262	1,4,5,6,8	3,266	4	1,5,6,8	3,282	20	1,5,8	3,379	117
80%	1,2,4,5,6,8	3,732	1,4,5,6,8	3,737	5	1,5,6,8	3,755	23	1,5,8	3,880	148
90%	1,2,4,5,6,8	4,215	1,4,5,6,8	4,220	5	1,5,6,8	4,241	26	1,5,8	4,381	166

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,8	541	62	8	590	111
5,8	1,064	123	8	1,160	219
5,8	1,584	183	8	1,728	327
5,8	2,115	245	8	2,307	438
5,8	2,640	306	8	2,881	546
5,8	3,159	365	8	3,447	653
5,8	3,699	438	8	4,025	763
1,8	4,228	496	8	4,594	862
1,8	4,792	577	8	5,163	948

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

100% Training Capacity											
Training	Optimal		5 Location Max			4 Location Max			3 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	1,2,4,5,6,8	479	1,4,5,6,8	479	1	1,5,6,8	482	3	1,5,8	494	16
20%	1,2,4,5,6,8	941	1,4,5,6,8	942	1	1,5,6,8	947	6	1,5,8	972	31
30%	1,2,4,5,6,8	1,401	1,4,5,6,8	1,403	2	1,5,6,8	1,409	9	1,5,8	1,446	46
40%	1,2,4,5,6,8	1,869	1,4,5,6,8	1,872	2	1,5,6,8	1,881	12	1,5,8	1,931	61
50%	1,2,4,5,6,8	2,334	1,4,5,6,8	2,338	3	1,5,6,8	2,349	15	1,5,8	2,411	76
60%	1,2,4,5,6,8	2,794	1,4,5,6,8	2,798	4	1,5,6,8	2,811	17	1,5,8	2,885	91
70%	1,2,4,5,6,8	3,262	1,4,5,6,8	3,266	4	1,5,6,8	3,282	20	1,5,8	3,370	108
80%	1,2,4,5,6,8	3,723	1,4,5,6,8	3,728	5	1,5,6,8	3,746	23	1,5,8	3,861	138
90%	1,2,4,5,6,8	4,197	1,4,5,6,8	4,202	5	1,5,6,8	4,223	26	1,5,8	4,363	166

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,8	541	62	8	590	111
5,8	1,064	123	8	1,160	219
5,8	1,584	183	8	1,728	327
5,8	2,115	245	8	2,307	438
5,8	2,640	306	8	2,881	546
5,8	3,159	365	8	3,447	653
5,8	3,690	429	8	4,025	763
5,8	4,227	504	8	4,594	870
1,8	4,774	577	8	5,163	967

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

Appendix I: Phase 6 Model Output

10% Training Capacity

Training	Optimal		7 Location Max			6 Location Max			5 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,5,7,8	569	2,5,7,8	569	0	2,5,7,8	569	0	2,5,7,8	569	0
20%	2,5,7,8	1,158	2,5,7,8	1,158	0	2,5,7,8	1,158	0	2,5,7,8	1,158	0
30%	1,2,4,5,6,7,8	1,789	1,2,4,5,6,7,8	1,789	0	2,4,5,6,7,8	1,789	0	2,5,6,7,8	1,798	9
40%	1,2,3,4,5,6,7,8	2,581	1,2,3,5,6,7,8	2,603	22	Infeasible	n/a	n/a	Infeasible	n/a	n/a
50%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
60%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
70%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
80%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
90%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

4 Location Max			3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
2,5,7,8	569	0	5,7,8	578	9	5,8	612	43	8	740	172
2,5,7,8	1,158	0	5,7,8	1,175	18	7,8	1,347	189	Infeasible	n/a	n/a
3,5,7,8	1,894	105	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

20% Training Capacity

Training	Optimal		7 Location Max			6 Location Max			5 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,5,7,8	550	2,5,7,8	550	0	2,5,7,8	550	0	2,5,7,8	550	0
20%	2,5,7,8	1,126	2,5,7,8	1,126	0	2,5,7,8	1,126	0	2,5,7,8	1,126	0
30%	2,5,7,8	1,710	2,5,7,8	1,710	0	2,5,7,8	1,710	0	2,5,7,8	1,710	0
40%	2,5,7,8	2,306	2,5,7,8	2,306	0	2,5,7,8	2,306	0	2,5,7,8	2,306	0
50%	2,5,7,8	2,895	2,5,7,8	2,895	0	2,5,7,8	2,895	0	2,5,7,8	2,895	0
60%	1,2,4,5,6,7,8	3,571	1,2,4,5,6,7,8	3,571	0	2,4,5,6,7,8	3,571	0	2,5,6,7,8	3,589	18
70%	1,2,4,5,6,7,8	4,328	1,2,4,5,6,7,8	4,328	0	1,2,4,6,7,8	4,352	24	3,5,6,7,8	4,553	224
80%	1,2,3,4,5,6,7,8	5,133	1,2,3,5,6,7,8	5,178	45	Infeasible	n/a	n/a	Infeasible	n/a	n/a
90%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

4 Location Max			3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
2,5,7,8	550	0	5,7,8	557	8	5,8	580	30	8	740	191
2,5,7,8	1,126	0	5,7,8	1,143	17	5,8	1,210	84	8	1,467	341
2,5,7,8	1,710	0	5,7,8	1,735	25	5,8	1,860	149	8	2,187	477
2,5,7,8	2,306	0	5,7,8	2,341	35	7,8	2,683	376	Infeasible	n/a	n/a
2,5,7,8	2,895	0	2,7,8	3,323	428	Infeasible	n/a	n/a	Infeasible	n/a	n/a
3,5,7,8	3,778	207	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

30% Training Capacity											
Training	Optimal		6 Location Max			5 Location Max			4 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,5,7,8	548	2,5,7,8	548	0	2,5,7,8	548	0	2,5,7,8	548	0
20%	2,5,7,8	1,101	2,5,7,8	1,101	0	2,5,7,8	1,101	0	2,5,7,8	1,101	0
30%	2,5,7,8	1,679	2,5,7,8	1,679	0	2,5,7,8	1,679	0	2,5,7,8	1,679	0
40%	2,5,7,8	2,275	2,5,7,8	2,275	0	2,5,7,8	2,275	0	2,5,7,8	2,275	0
50%	2,5,7,8	2,863	2,5,7,8	2,863	0	2,5,7,8	2,863	0	2,5,7,8	2,863	0
60%	2,5,7,8	3,447	2,5,7,8	3,447	0	2,5,7,8	3,447	0	2,5,7,8	3,447	0
70%	2,5,7,8	4,041	2,5,7,8	4,041	0	2,5,7,8	4,041	0	2,5,7,8	4,041	0
80%	2,4,5,6,7,8	4,642	2,4,5,6,7,8	4,642	0	2,4,5,7,8	4,643	1	2,5,7,8	4,649	7
90%	1,2,4,5,6,7,8	5,351	2,4,5,6,7,8	5,351	1	2,4,5,7,8	5,378	27	3,5,7,8	5,659	309

3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,7,8	556	8	5,8	574	26	8	740	193
5,7,8	1,115	14	5,8	1,176	75	8	1,467	367
5,7,8	1,704	25	5,8	1,804	125	8	2,187	508
5,7,8	2,308	33	5,8	2,462	186	8	2,922	647
5,7,8	2,903	41	5,8	3,123	260	Infeasible	n/a	n/a
5,7,8	3,499	52	7,8	4,009	562	Infeasible	n/a	n/a
5,7,8	4,108	67	Infeasible	n/a	n/a	Infeasible	n/a	n/a
6,7,8	5,442	800	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

40% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,5,7,8	548	5,7,8	556	8	5,8	574	26	8	740	193
20%	2,5,7,8	1,088	5,7,8	1,102	14	5,8	1,146	58	8	1,467	380
30%	2,5,7,8	1,650	5,7,8	1,673	23	5,8	1,768	118	8	2,187	537
40%	2,5,7,8	2,244	5,7,8	2,277	33	5,8	2,410	166	8	2,922	678
50%	2,5,7,8	2,832	5,7,8	2,872	41	5,8	3,057	225	8	3,645	814
60%	2,5,7,8	3,416	5,7,8	3,465	49	5,8	3,712	296	8	4,366	950
70%	2,5,7,8	4,009	5,7,8	4,066	57	5,8	4,379	370	Infeasible	n/a	n/a
80%	2,5,7,8	4,596	5,7,8	4,665	69	7,8	5,345	749	Infeasible	n/a	n/a
90%	2,5,7,8	5,183	5,7,8	5,266	84	7,8	6,009	827	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

50% Training Capacity											
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,5,7,8	548	5,7,8	556	8	5,8	574	26	8	681	133
20%	2,5,7,8	1,085	5,7,8	1,099	14	5,8	1,135	51	8	1,467	383
30%	2,5,7,8	1,632	5,7,8	1,654	21	5,8	1,737	104	8	2,187	555
40%	2,5,7,8	2,213	5,7,8	2,246	33	5,8	2,373	160	8	2,922	709
50%	2,5,7,8	2,800	5,7,8	2,841	41	5,8	3,007	207	8	3,645	845
60%	2,5,7,8	3,385	5,7,8	3,434	49	5,8	3,650	265	8	4,366	981
70%	2,5,7,8	3,978	5,7,8	4,035	57	7,8	4,310	332	8	5,096	1,118
80%	2,5,7,8	4,565	5,7,8	4,630	65	7,8	4,972	407	Infeasible	n/a	n/a
90%	2,5,7,8	5,151	5,7,8	5,223	73	7,8	6,007	857	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

60% Training Capacity

Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,5,7,8	548	5,7,8	556	8	5,8	574	26	5	681	133
20%	2,5,7,8	1,085	5,7,8	1,099	14	5,8	1,135	51	8	1,467	383
30%	2,5,7,8	1,622	5,7,8	1,643	21	5,8	1,708	87	8	2,187	566
40%	2,5,7,8	2,193	5,7,8	2,221	28	5,8	2,342	149	8	2,922	729
50%	2,5,7,8	2,769	5,7,8	2,810	41	5,8	2,969	200	8	3,645	876
60%	2,5,7,8	3,354	5,7,8	3,403	49	5,8	3,601	247	8	4,366	1,013
70%	2,5,7,8	3,947	5,7,8	4,004	57	5,8	4,253	306	8	5,096	1,149
80%	2,5,7,8	4,534	5,7,8	4,599	65	5,8	4,903	369	8	5,821	1,287
90%	2,5,7,8	5,119	5,7,8	5,192	73	5,8	5,562	443	8	6,542	1,423

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

70% Training Capacity

Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,5,7,8	548	5,7,8	556	8	5,8	574	26	5	681	133
20%	2,5,7,8	1,085	5,7,8	1,099	14	5,8	1,135	51	8	1,467	383
30%	2,5,7,8	1,617	5,7,8	1,639	21	5,8	1,693	76	8	2,187	570
40%	2,5,7,8	2,177	5,7,8	2,205	28	5,8	2,310	133	8	2,922	745
50%	2,5,7,8	2,744	5,7,8	2,779	35	5,8	2,937	193	8	3,645	901
60%	2,5,7,8	3,323	5,7,8	3,371	49	5,8	3,562	240	8	4,366	1,044
70%	2,5,7,8	3,916	5,7,8	3,972	57	5,8	4,204	288	8	5,096	1,180
80%	2,5,7,8	4,503	5,7,8	4,568	65	5,8	4,850	347	8	5,821	1,318
90%	2,5,7,8	5,088	5,7,8	5,161	73	5,8	5,496	408	8	6,542	1,454

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

80% Training Capacity

Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,5,7,8	548	5,7,8	556	8	5,8	574	26	5	681	133
20%	2,5,7,8	1,085	5,7,8	1,099	14	5,8	1,135	51	8	1,467	383
30%	2,5,7,8	1,617	5,7,8	1,639	21	5,8	1,693	75	8	2,187	570
40%	2,5,7,8	2,167	5,7,8	2,195	28	5,8	2,282	115	8	2,922	755
50%	2,5,7,8	2,728	5,7,8	2,763	35	5,8	2,906	178	8	3,645	917
60%	2,5,7,8	3,296	5,7,8	3,340	45	5,8	3,530	235	8	4,366	1,071
70%	2,5,7,8	3,884	5,7,8	3,941	57	5,8	4,164	279	8	5,096	1,211
80%	2,5,7,8	4,472	5,7,8	4,536	65	5,8	4,800	329	8	5,821	1,349
90%	2,5,7,8	5,057	5,7,8	5,130	73	5,8	5,444	387	8	6,542	1,485

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

90% Training Capacity

Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,5,7,8	548	5,7,8	556	8	5,8	574	26	5	681	133
20%	2,5,7,8	1,085	5,7,8	1,099	14	5,8	1,135	51	5	1,347	262
30%	2,5,7,8	1,617	5,7,8	1,639	21	5,8	1,693	75	8	2,187	570
40%	2,5,7,8	2,161	5,7,8	2,190	28	5,8	2,266	105	8	2,922	760
50%	2,5,7,8	2,714	5,7,8	2,749	35	5,8	2,874	160	8	3,645	931
60%	2,5,7,8	3,277	5,7,8	3,319	42	5,8	3,499	222	8	4,366	1,089
70%	2,5,7,8	3,856	5,7,8	3,910	54	5,8	4,132	276	8	5,096	1,240
80%	2,5,7,8	4,440	5,7,8	4,505	65	5,8	4,759	319	8	5,821	1,381
90%	2,5,7,8	5,026	5,7,8	5,099	73	5,8	5,395	370	8	6,542	1,517

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

100% Training Capacity										
Training	Optimal		3 Location Max			2 Location Max			1 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,5,7,8	548	5,7,8	556	8	5,8	574	26	5	681	133
20%	2,5,7,8	1,085	5,7,8	1,099	14	5,8	1,135	51	5	1,347	262
30%	2,5,7,8	1,617	5,7,8	1,639	21	5,8	1,693	75	8	2,187	570
40%	2,5,7,8	2,161	5,7,8	2,190	28	5,8	2,261	100	8	2,922	760
50%	2,5,7,8	2,704	5,7,8	2,739	35	5,8	2,848	143	8	3,645	941
60%	2,5,7,8	3,260	5,7,8	3,302	42	5,8	3,467	206	8	4,366	1,106
70%	2,5,7,8	3,834	5,7,8	3,883	49	5,8	4,100	266	8	5,096	1,262
80%	2,5,7,8	4,410	5,7,8	4,474	64	5,8	4,728	318	8	5,821	1,411
90%	2,5,7,8	4,995	5,7,8	5,067	73	5,8	5,353	359	8	6,542	1,548

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

Appendix J: Phase 7 Model Output

10% Training Capacity											
Training	Optimal		7 Location Max			6 Location Max			5 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,3,4,5,6,7,8	504	2,3,4,5,6,7,8	504	0	2,3,4,5,7,8	504	0	3,4,5,7,8	505	2
20%	2,3,4,5,6,7,8	996	5,8	1,046	50	5,8	1,046	50	5,8	1,046	50
30%	2,3,4,5,6,7,8	1,488	2,3,5,6,7,8	1,510	21	2,3,5,6,7,8	1,510	21	4,5,7,8	1,511	23
40%	2,3,4,5,6,7,8	2,012	1,3,6,7,8	2,102	90	1,3,6,7,8	2,102	90	1,3,6,7,8	2,102	90
50%	1,2,3,4,5,6,7,8	2,596	1,2,3,6,7,8	2,701	105	1,2,3,6,7,8	2,701	105	Infeasible	n/a	n/a
60%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
70%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
80%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
90%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
4 Location Max			3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
4,5,7,8	510	6	4,5,8	514	11	5,8	522	19	8	560	56
5,8	1,046	50	5,8	1,046	50	5,8	1,046	50	Infeasible	n/a	n/a
4,5,7,8	1,511	23	4,7,8	1,533	44	Infeasible	n/a	n/a	Infeasible	n/a	n/a
1,3,7,8	2,176	164	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

20% Training Capacity											
Training	Optimal		7 Location Max			6 Location Max			5 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,3,4,5,6,7,8	504	2,3,4,5,6,7,8	504	0	2,3,4,5,7,8	504	0	3,4,5,7,8	505	2
20%	2,3,4,5,6,7,8	994	2,3,4,5,6,7,8	994	0	2,3,4,5,7,8	995	0	3,4,5,7,8	998	4
30%	2,3,4,5,6,7,8	1,480	2,3,4,5,6,7,8	1,480	0	2,3,4,5,7,8	1,480	0	3,4,5,7,8	1,485	5
40%	2,3,4,5,6,7,8	1,973	2,3,4,5,6,7,8	1,973	0	5,8	2,070	97	5,8	2,070	97
50%	2,3,4,5,6,7,8	2,469	2,3,4,5,6,7,8	2,469	0	2,3,5,6,7,8	2,504	35	2,3,5,6,8	2,564	96
60%	2,3,4,5,6,7,8	2,956	2,3,4,5,6,7,8	2,956	0	2,3,6,7,8	3,560	604	2,3,6,7,8	3,560	604
70%	2,3,4,5,6,7,8	3,456	2,3,4,5,6,7,8	3,456	0	2,3,6,7,8	3,560	103	2,3,6,7,8	3,560	103
80%	2,3,4,5,6,7,8	3,997	2,3,4,5,6,7,8	3,997	0	1,3,6,7,8	4,175	177	1,3,6,7,8	4,175	177
90%	1,2,3,4,5,6,7,8	4,541	2,3,4,5,6,7,8	4,545	4	2,3,4,5,7,8	4,677	136	1,3,6,7,8	4,803	262
4 Location Max			3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
4,5,7,8	509,764	6	4,5,8	514	11	5,8	522	19	8	560	56
4,5,7,8	1,006,564	12	4,5,8	1,015	21	5,8	1,030	36	8	1,104	109
4,5,7,8	1,498,318	18	4,5,8	1,516	36	5,8	1,540	61	8	1,643	163
5,8	2,070,016	97	5,8	2,070	97	5,8	2,070	97	Infeasible	n/a	n/a
2,3,5,8	2,574,042	105	5,7,8	2,535	66	7,8	2,575	106	Infeasible	n/a	n/a
2,5,6,8	3,106,982	151	4,7,8	3,042	86	Infeasible	n/a	n/a	Infeasible	n/a	n/a
4,6,7,8	3,546,659	90	3,7,8	3,710	253	Infeasible	n/a	n/a	Infeasible	n/a	n/a
2,3,7,8	4,278,052	281	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
*Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

30% Training Capacity											
Training	Optimal		6 Location Max			5 Location Max			4 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,3,4,5,6,7,8	504	2,3,4,5,7,8	504	0	3,4,5,7,8	505	2	4,5,7,8	510	6
20%	2,3,4,5,6,7,8	994	2,3,4,5,7,8	995	0	3,4,5,7,8	998	4	4,5,7,8	1,007	12
30%	2,3,4,5,6,7,8	1,480	2,3,4,5,7,8	1,480	0	3,4,5,7,8	1,485	5	4,5,7,8	1,498	18
40%	2,3,4,5,6,7,8	1,970	2,3,4,5,7,8	1,970	0	3,4,5,7,8	1,977	7	4,5,7,8	1,993	23
50%	2,3,4,5,6,7,8	2,460	2,3,4,5,7,8	2,460	0	3,4,5,7,8	2,469	9	4,5,7,8	2,489	29
60%	2,3,4,5,6,7,8	2,944	5,7,8	3,089	145	5,7,8	3,089	145	5,7,8	3,089	145
70%	2,3,4,5,6,7,8	3,435	5,7,8	3,524	89	5,7,8	3,524	89	5,7,8	3,524	89
80%	2,3,4,5,6,7,8	3,931	2,5,6,7,8	4,018	87	2,5,6,7,8	4,018	87	2,5,6,8	4,650	719
90%	2,3,4,5,6,7,8	4,426	2,5,6,7,8	4,523	97	2,5,6,7,8	4,523	97	2,5,6,8	4,650	225
3 Location Max			2 Location Max			1 Location Max					
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)			
4,5,8	514	11	5,8	522	19	8	560	56			
4,5,8	1,015	21	5,8	1,030	36	8	1,104	109			
4,5,8	1,511	31	5,8	1,534	54	8	1,643	163			
4,5,8	2,010	40	5,8	2,039	69	8	2,184	214			
5,7,8	2,525	66	5,8	2,569	109	8	2,728	268			
5,7,8	3,089	145	5,8	3,089	145	Infeasible	n/a	n/a			
5,7,8	3,524	89	7,8	3,583	148	Infeasible	n/a	n/a			
2,5,8	4,167	235	7,8	4,097	166	Infeasible	n/a	n/a			
2,7,8	4,616	191	Infeasible	n/a	n/a	Infeasible	n/a	n/a			
* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

40% Training Capacity											
Training	Optimal		6 Location Max			5 Location Max			4 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,3,4,5,6,7,8	504	2,3,4,5,7,8	504	0	3,4,5,7,8	505	2	4,5,7,8	510	6
20%	2,3,4,5,6,7,8	994	2,3,4,5,7,8	995	0	3,4,5,7,8	998	4	4,5,7,8	1,007	12
30%	2,3,4,5,6,7,8	1,480	2,3,4,5,7,8	1,480	0	3,4,5,7,8	1,485	5	3,4,5,8	1,498	18
40%	2,3,4,5,6,7,8	1,970	2,3,4,5,7,8	1,970	0	3,4,5,7,8	1,977	7	4,5,7,8	1,993	23
50%	2,3,4,5,6,7,8	2,460	2,3,4,5,7,8	2,460	0	3,4,5,7,8	2,469	9	4,5,7,8	2,489	29
60%	2,3,4,5,6,7,8	2,939	2,3,4,5,7,8	2,939	0	3,4,5,7,8	2,950	11	4,5,7,8	2,974	35
70%	2,3,4,5,6,7,8	3,426	2,3,4,5,7,8	3,426	0	3,4,5,7,8	3,438	12	4,5,7,8	3,465	40
80%	2,3,4,5,6,7,8	3,921	5,8	4,113	192	5,8	4,113	192	5,8	4,113	192
90%	2,3,4,5,6,7,8	4,413	5,8	4,640	227	5,8	4,640	227	5,8	4,640	227
3 Location Max			2 Location Max			1 Location Max					
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)			
4,5,8	514	11	5,8	522	19	8	560	56			
4,5,8	1,015	21	5,8	1,030	36	8	1,104	109			
4,5,8	1,511	31	5,8	1,534	54	8	1,643	163			
4,5,8	2,010	40	5,8	2,039	69	8	2,184	214			
4,5,8	2,510	50	5,8	2,547	87	8	2,728	268			
4,5,8	3,008	69	5,8	3,056	117	8	3,259	320			
5,7,8	3,515	89	5,8	3,580	155	8	3,796	370			
5,8	4,113	192	5,8	4,113	192	Infeasible	n/a	n/a			
5,8	4,640	227	5,8	4,640	227	Infeasible	n/a	n/a			
* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins											

50% Training Capacity											
Training	Optimal		6 Location Max			5 Location Max			4 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,3,4,5,6,7,8	504	2,3,4,5,7,8	504	0	3,4,5,7,8	505	2	4,5,7,8	510	6
20%	2,3,4,5,6,7,8	994	2,3,4,5,7,8	995	0	3,4,5,7,8	998	4	4,5,7,8	1,007	12
30%	2,3,4,5,6,7,8	1,480	2,3,4,5,7,8	1,480	0	3,4,5,7,8	1,485	5	3,4,5,8	1,498	18
40%	2,3,4,5,6,7,8	1,970	2,3,4,5,7,8	1,970	0	3,4,5,7,8	1,977	7	4,5,7,8	1,993	23
50%	2,3,4,5,6,7,8	2,460	2,3,4,5,7,8	2,460	0	3,4,5,7,8	2,469	9	4,5,7,8	2,489	29
60%	2,3,4,5,6,7,8	2,939	2,3,4,5,7,8	2,939	0	3,4,5,7,8	2,950	11	4,5,7,8	2,974	35
70%	2,3,4,5,6,7,8	3,424	2,3,4,5,7,8	3,425	0	3,4,5,7,8	3,436	12	4,5,7,8	3,464	40
80%	2,3,4,5,6,7,8	3,914	2,3,4,5,7,8	3,915	1	3,4,5,7,8	3,929	14	4,5,7,8	3,960	46
90%	2,3,4,5,6,7,8	4,404	2,3,4,5,7,8	4,404	1	3,4,5,7,8	4,420	16	4,5,7,8	4,455	52

3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
4,5,8	514	11	5,8	522	19	8	560	56
4,5,8	1,015	21	5,8	1,030	36	8	1,104	109
4,5,8	1,511	31	5,8	1,534	54	8	1,643	163
4,5,8	2,010	40	5,8	2,039	69	8	2,184	214
4,5,8	2,510	50	5,8	2,547	87	8	2,728	268
4,5,8	2,999	60	5,8	3,043	104	8	3,259	320
4,5,8	3,493	69	5,8	3,547	123	8	3,796	371
5,7,8	4,018	103	5,8	4,079	165	8	4,339	425
5,7,8	4,519	116	7,8	4,606	202	8	4,878	475

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

60% Training Capacity											
Training	Optimal		6 Location Max			5 Location Max			4 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,3,4,5,6,7,8	504	2,3,4,5,7,8	504	0	3,4,5,7,8	505	2	4,5,7,8	510	6
20%	2,3,4,5,6,7,8	994	2,3,4,5,7,8	995	0	3,4,5,7,8	998	4	4,5,7,8	1,007	12
30%	2,3,4,5,6,7,8	1,480	2,3,4,5,7,8	1,480	0	3,4,5,7,8	1,485	5	3,4,5,8	1,498	18
40%	2,3,4,5,6,7,8	1,970	2,3,4,5,7,8	1,970	0	3,4,5,7,8	1,977	7	4,5,7,8	1,993	23
50%	2,3,4,5,6,7,8	2,460	2,3,4,5,7,8	2,460	0	3,4,5,7,8	2,469	9	4,5,7,8	2,489	29
60%	2,3,4,5,6,7,8	2,939	2,3,4,5,7,8	2,939	0	3,4,5,7,8	2,950	11	4,5,7,8	2,974	35
70%	2,3,4,5,6,7,8	3,424	2,3,4,5,7,8	3,425	0	3,4,5,7,8	3,436	12	4,5,7,8	3,464	40
80%	2,3,4,5,6,7,8	3,914	2,3,4,5,7,8	3,915	1	3,4,5,7,8	3,929	14	4,5,7,8	3,960	46
90%	2,3,4,5,6,7,8	4,401	2,3,4,5,7,8	4,401	1	3,4,5,7,8	4,416	16	4,5,7,8	4,452	52

3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
4,5,8	514	11	5,8	522	19	8	560	56
4,5,8	1,015	21	5,8	1,030	36	8	1,104	109
4,5,8	1,511	31	5,8	1,534	54	8	1,643	163
4,5,8	2,010	40	5,8	2,039	69	8	2,184	214
4,5,8	2,510	50	5,8	2,547	87	8	2,728	268
4,5,8	2,999	60	5,8	3,043	104	8	3,259	320
4,5,8	3,493	69	5,8	3,543	119	8	3,796	371
4,5,8	3,993	79	5,8	4,052	138	8	4,339	425
4,5,8	4,503	102	5,8	4,573	173	8	4,878	478

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

70-100% Training Capacity											
Training	Optimal		6 Location Max			5 Location Max			4 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	2,3,4,5,6,7,8	504	2,3,4,5,7,8	504	0	3,4,5,7,8	505	2	4,5,7,8	510	6
20%	2,3,4,5,6,7,8	994	2,3,4,5,7,8	995	0	3,4,5,7,8	998	4	4,5,7,8	1,007	12
30%	2,3,4,5,6,7,8	1,480	2,3,4,5,7,8	1,480	0	3,4,5,7,8	1,485	5	3,4,5,8	1,498	18
40%	2,3,4,5,6,7,8	1,970	2,3,4,5,7,8	1,970	0	3,4,5,7,8	1,977	7	4,5,7,8	1,993	23
50%	2,3,4,5,6,7,8	2,460	2,3,4,5,7,8	2,460	0	3,4,5,7,8	2,469	9	4,5,7,8	2,489	29
60%	2,3,4,5,6,7,8	2,939	2,3,4,5,7,8	2,939	0	3,4,5,7,8	2,950	11	4,5,7,8	2,974	35
70%	2,3,4,5,6,7,8	3,424	2,3,4,5,7,8	3,425	0	3,4,5,7,8	3,436	12	4,5,7,8	3,464	40
80%	2,3,4,5,6,7,8	3,914	2,3,4,5,7,8	3,915	1	3,4,5,7,8	3,929	14	4,5,7,8	3,960	46
90%	2,3,4,5,6,7,8	4,401	2,3,4,5,7,8	4,401	1	3,4,5,7,8	4,416	16	4,5,7,8	4,452	52

3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
4,5,8	514	11	5,8	522	19	8	560	56
4,5,8	1,015	21	5,8	1,030	36	8	1,104	109
4,5,8	1,511	31	5,8	1,534	54	8	1,643	163
4,5,8	2,010	40	5,8	2,039	69	8	2,184	214
4,5,8	2,510	50	5,8	2,547	87	8	2,728	268
4,5,8	2,999	60	5,8	3,043	104	8	3,259	320
4,5,8	3,493	69	5,8	3,543	119	8	3,796	371
4,5,8	3,993	79	5,8	4,052	138	8	4,339	425
4,5,8	4,489	89	5,8	4,554	154	8	4,878	478

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

Appendix K: Phase 8 Model Output

10% Training Capacity													
Training	Optimal		6 Location Max			5 Location Max			4 Location Max				
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)		
10%	4,5,6,7,8	474	4,5,6,7,8	474	0	4,5,6,7,8	474	0	4,5,7,8	474	0		
20%	4,5,6,7,8	969	4,5,6,7,8	969	0	4,5,6,7,8	969	0	4,5,7,8	976	7		
30%	2,4,5,6,7,8	1,482	2,4,5,6,7,8	1,482	0	4,5,6,7,8	1,484	3	5,6,7,8	1,494	12		
40%	2,4,5,6,7,8	2,021	2,4,5,6,7,8	2,021	0	4,5,6,7,8	2,025	3	5,6,7,8	2,036	14		
50%	1,2,4,5,6,7,8	2,578	2,3,5,6,7,8	2,615	37	Infeasible	n/a	n/a	Infeasible	n/a	n/a		
60%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a		
70%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a		
80%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a		
90%	Infeasible	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a		

3 Location Max			2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
4,5,7	507	33	5,7	545	71	8	755	281
6,7,8	1,037	68	7,8	1,155	186	8	1,486	517
6,7,8	1,573	91	7,8	1,768	286	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

20% Training Capacity												
Training	Optimal		5 Location Max			4 Location Max			3 Location Max			
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	
10%	4,5,6,7,8	463	4,5,6,7,8	463	0	4,5,7,8	463	0	4,5,7	474	11	
20%	4,5,6,7,8	933	4,5,6,7,8	933	0	4,5,7,8	934	1	4,5,7	997	64	
30%	4,5,6,7,8	1,423	4,5,6,7,8	1,423	0	4,5,7,8	1,423	1	4,5,7	1,528	106	
40%	4,5,6,7,8	1,922	4,5,6,7,8	1,922	0	4,5,7,8	1,930	8	4,7,8	2,053	131	
50%	4,5,6,7,8	2,434	4,5,6,7,8	2,434	0	5,6,7,8	2,452	18	4,7,8	2,652	219	
60%	2,4,5,6,7,8	2,944	4,5,6,7,8	2,949	5	5,6,7,8	2,969	25	6,7,8	3,126	183	
70%	2,4,5,6,7,8	3,477	4,5,6,7,8	3,483	6	5,6,7,8	3,503	26	6,7,8	3,680	202	
80%	2,4,5,6,7,8	4,020	4,5,6,7,8	4,026	7	5,6,7,8	4,047	27	Infeasible	n/a	n/a	
90%	2,4,5,6,7,8	4,558	1,5,6,7,8	4,615	57	Infeasible	n/a	n/a	Infeasible	n/a	n/a	

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,7	508	45	7	630	166
5,7	1,074	140	8	1,486	553
6,7	1,690	268	8	2,217	794
7,8	2,292	370	8	2,950	1,028
7,8	2,892	458	Infeasible	n/a	n/a
7,8	3,512	568	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a
Infeasible	n/a	n/a	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

30% Training Capacity												
Training Demand	Optimal		5 Location Max			4 Location Max			3 Location Max			
	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	
10%	4,5,7,8	462	4,5,7,8	462	0	4,5,7,8	462	0	4,5,7	470	7	
20%	4,5,6,7,8	920	4,5,6,7,8	920	0	4,5,7,8	920	0	4,5,7	960	40	
30%	4,5,6,7,8	1,391	4,5,6,7,8	1,391	0	4,5,7,8	1,392	1	4,5,7	1,486	95	
40%	4,5,6,7,8	1,881	4,5,6,7,8	1,881	0	4,5,7,8	1,882	1	4,5,7	2,017	136	
50%	4,5,6,7,8	2,377	4,5,6,7,8	2,377	0	4,5,7,8	2,378	1	4,7,8	2,546	170	
60%	4,5,6,7,8	2,869	4,5,6,7,8	2,869	0	4,5,7,8	2,883	13	4,7,8	3,068	198	
70%	4,5,6,7,8	3,376	4,5,6,7,8	3,376	0	5,6,7,8	3,402	27	6,7,8	3,602	226	
80%	4,5,6,7,8	3,890	4,5,6,7,8	3,890	0	5,6,7,8	3,917	27	6,7,8	4,145	255	
90%	2,4,5,6,7,8	4,405	4,5,6,7,8	4,413	8	4,5,7,8	4,581	176	6,7,8	4,679	273	

2 Location Max			1 Location Max		
Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
5,7	495	32	7	630	167
5,7	1,034	114	7	1,241	321
5,7	1,600	209	8	2,217	825
6,7	2,228	347	8	2,950	1,069
7,8	2,859	482	8	3,685	1,308
7,8	3,422	553	8	4,405	1,536
7,8	4,016	640	Infeasible	n/a	n/a
7,8	4,623	733	Infeasible	n/a	n/a
7,8	5,255	849	Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

40% Training Capacity											
Training Demand	Optimal		4 Location Max			3 Location Max			2 Location Max		
	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	4,5,7,8	462	4,5,7,8	462	0	4,5,7	470	7	5,7	495	32
20%	4,5,6,7,8	912	4,5,7,8	912	0	4,5,7	932	20	5,7	1,000	88
30%	4,5,6,7,8	1,377	4,5,7,8	1,378	1	4,5,7	1,449	72	5,7	1,560	183
40%	4,5,6,7,8	1,852	4,5,7,8	1,853	1	4,5,7	1,978	126	5,7	2,129	278
50%	4,5,6,7,8	2,340	4,5,7,8	2,341	1	4,5,7	2,510	170	5,7	2,717	377
60%	4,5,6,7,8	2,827	4,5,7,8	2,829	2	4,5,7	3,036	209	6,7	3,359	532
70%	4,5,6,7,8	3,317	4,5,7,8	3,319	2	4,7,8	3,547	230	7,8	3,983	666
80%	4,5,6,7,8	3,822	4,5,7,8	3,836	14	4,7,8	4,080	259	7,8	4,559	737
90%	4,5,6,7,8	4,327	5,6,7,8	4,363	36	6,7,8	4,619	292	7,8	5,151	824

1 Location Max		
Locations*	Cost ($000)	Δ ($000)
7	630	167
7	1,241	329
7	1,851	475
8	2,950	1,098
8	3,685	1,345
8	4,405	1,578
8	5,130	1,813
8	5,869	2,047
Infeasible	n/a	n/a

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

50% Training Capacity												
Training	Optimal		4 Location Max			3 Location Max			2 Location Max			
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	4,5,7,8	462	4,5,7,8	462	0	4,5,7	470	7	5,7	495	32
20%	4,5,7,8	911	4,5,7,8	911	0	4,5,7	925	14	5,7	977	67
30%	4,5,6,7,8	1,367	4,5,7,8	1,367	0	4,5,7	1,417	50	5,7	1,522	155
40%	4,5,6,7,8	1,837	4,5,7,8	1,838	1	4,5,7	1,940	103	5,7	2,089	252
50%	4,5,6,7,8	2,312	4,5,7,8	2,314	1	4,5,7	2,470	158	5,7	2,659	346
60%	4,5,6,7,8	2,790	4,5,7,8	2,792	2	4,5,7	2,993	203	5,7	3,236	446
70%	4,5,6,7,8	3,280	4,5,7,8	3,282	2	4,5,7	3,519	238	6,7	3,891	611
80%	4,5,6,7,8	3,778	4,5,7,8	3,780	2	4,7,8	4,057	278	6,7	4,496	718
90%	4,5,6,7,8	4,267	4,5,7,8	4,270	3	5,7,8	4,658	391	7,8	5,117	850

1 Location Max		
Locations*	Cost ($000)	Δ ($000)
5	543	80
7	1,241	331
7	1,851	484
7	2,464	627
8	3,685	1,373
8	4,405	1,615
8	5,130	1,850
8	5,869	2,091
8	6,592	2,325

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

60% Training Capacity											
Training	Optimal		4 Location Max			3 Location Max			2 Location Max		
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	4,5,7,8	462	4,5,7,8	462	0	4,5,7	470	7	5,7	495	32
20%	4,5,7,8	911	4,5,7,8	911	0	4,5,7	925	14	5,7	974	63
30%	4,5,6,7,8	1,360	4,5,7,8	1,360	0	4,5,7	1,389	29	5,7	1,490	131
40%	4,5,6,7,8	1,825	4,5,7,8	1,826	1	4,5,7	1,904	79	5,7	2,050	225
50%	4,5,6,7,8	2,298	4,5,7,8	2,299	1	4,5,7	2,432	134	5,7	2,619	321
60%	4,5,6,7,8	2,765	4,5,7,8	2,767	2	4,5,7	2,953	188	5,7	3,179	414
70%	4,5,6,7,8	3,244	4,5,7,8	3,246	2	4,5,7	3,479	236	5,7	3,760	517
80%	4,5,6,7,8	3,741	4,5,7,8	3,744	2	4,5,7	4,013	272	6,7	4,433	691
90%	4,5,6,7,8	4,230	4,5,7,8	4,233	3	4,5,7	4,542	311	6,7	5,027	797

1 Location Max		
Locations*	Cost ($000)	Δ ($000)
7	543	80
7	1,241	331
7	1,851	492
7	2,464	639
7	3,077	779
8	4,405	1,640
8	5,130	1,887
8	5,869	2,128
8	6,592	2,362

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

70% Training Capacity											
Training Demand	Optimal		4 Location Max			3 Location Max			2 Location Max		
	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	4,5,7,8	462	4,5,7,8	462	0	4,5,7	470	7	5,7	495	32
20%	4,5,7,8	911	4,5,7,8	911	0	4,5,7	925	14	5,7	974	63
30%	4,5,7,8	1,358	4,5,7,8	1,358	0	4,5,7	1,379	21	5,7	1,463	105
40%	4,5,6,7,8	1,817	4,5,7,8	1,817	0	4,5,7	1,876	59	5,7	2,014	197
50%	4,5,6,7,8	2,284	4,5,7,8	2,285	1	4,5,7	2,395	111	5,7	2,579	295
60%	4,5,6,7,8	2,750	4,5,7,8	2,752	2	4,5,7	2,915	164	5,7	3,138	388
70%	4,5,6,7,8	3,220	4,5,7,8	3,222	2	4,5,7	3,440	219	5,7	3,702	482
80%	4,5,6,7,8	3,705	4,5,7,8	3,707	2	4,5,7	3,974	269	5,7	4,292	588
90%	4,5,6,7,8	4,194	4,5,7,8	4,196	3	4,5,7	4,498	305	5,7	4,873	680

1 Location Max		
Locations*	Cost ($000)	Δ ($000)
5	543	80
5	1,068	158
7	1,851	494
7	2,464	647
7	3,077	793
7	3,680	930
8	5,130	1,910
8	5,869	2,164
8	6,592	2,399

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

80% Training Capacity											
Training Demand	Optimal		4 Location Max			3 Location Max			2 Location Max		
	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)
10%	4,5,7,8	462	4,5,7,8	462	0	4,5,7	470	7	5,7	495	32
20%	4,5,7,8	911	4,5,7,8	911	0	4,5,7	925	14	5,7	974	63
30%	4,5,7,8	1,358	4,5,7,8	1,358	0	4,5,7	1,390	32	5,7	1,452	94
40%	4,5,6,7,8	1,810	4,5,7,8	1,810	0	4,5,7	1,849	39	5,7	1,983	174
50%	4,5,6,7,8	2,275	4,5,7,8	2,276	1	4,5,7	2,364	89	5,7	2,542	267
60%	4,5,6,7,8	2,736	4,5,7,8	2,738	2	4,5,7	2,878	142	5,7	3,099	363
70%	4,5,6,7,8	3,206	4,5,7,8	3,208	2	4,5,7	3,401	195	5,7	3,662	456
80%	4,5,6,7,8	3,683	4,5,7,8	3,685	2	4,5,7	3,934	251	5,7	4,234	551
90%	4,5,6,7,8	4,157	4,5,7,8	4,159	3	4,5,7	4,459	302	5,7	4,815	658

1 Location Max		
Locations*	Cost ($000)	Δ ($000)
5	543	80
5	1,068	158
7	1,851	494
7	2,464	655
7	3,077	803
7	3,680	944
8	5,130	1,924
8	5,869	2,186
8	6,592	2,436

* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

90% Training Capacity													
Training	Optimal		4 Location Max			3 Location Max			2 Location Max				
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)		
10%	4,5,7,8	462	4,5,7,8	462	0	4,5,7	470	7	5,7	495	32		
20%	4,5,7,8	911	4,5,7,8	911	0	4,5,7	925	14	5,7	974	63		
30%	4,5,7,8	1,358	4,5,7,8	1,358	0	4,5,7	1,379	21	5,7	1,452	94		
40%	4,5,7,8	1,807	4,5,7,8	1,807	0	4,5,7	1,838	31	5,7	1,955	148		
50%	4,5,6,7,8	2,267	4,5,7,8	2,267	0	4,5,7	2,336	68	5,7	2,505	238		
60%	4,5,6,7,8	2,725	4,5,7,8	2,726	1	4,5,7	2,843	117	5,7	3,061	335		
70%	4,5,6,7,8	3,192	4,5,7,8	3,194	2	4,5,7	3,364	173	5,7	3,623	431		
80%	4,5,6,7,8	3,669	4,5,7,8	3,671	2	4,5,7	3,895	226	5,7	4,194	525		
90%	4,5,6,7,8	4,138	4,5,7,8	4,140	3	4,5,7	4,420	282	5,7	4,757	619		

1 Location Max		
Locations*	Cost ($000)	Δ ($000)
5	543	80
5	1,068	158
7	1,851	494
7	2,464	658
7	3,077	810
7	3,680	955
7	4,288	1,096
7	4,903	1,235
8	6,592	2,455

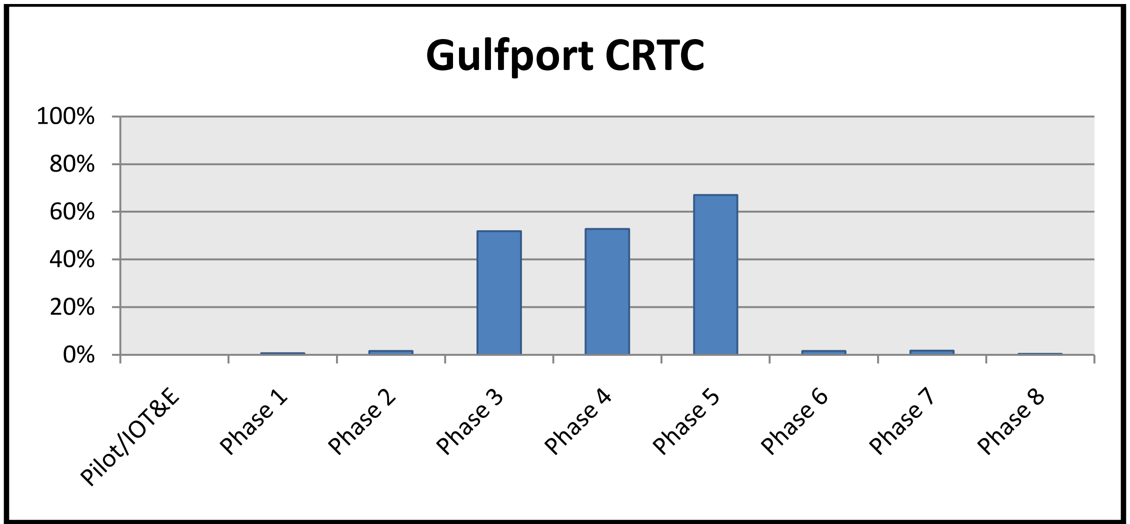
* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

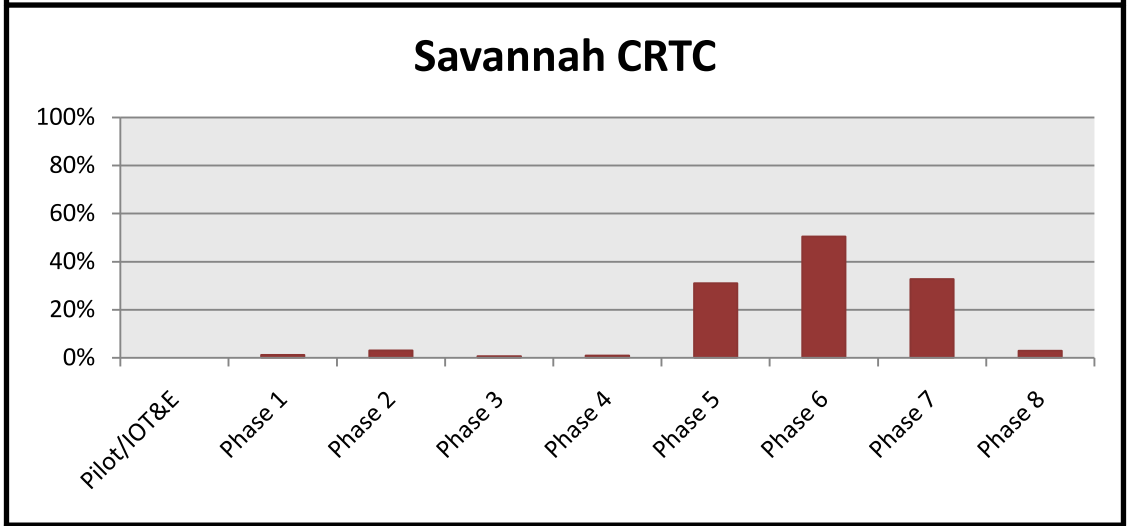
100% Training Capacity												
Training	Optimal		4 Location Max			3 Location Max			2 Location Max			
Demand	Locations*	Cost ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	Locations*	Cost ($000)	Δ ($000)	
10%	4,5,7,8	462	4,5,7,8	462	0	4,5,7	470	7	5,7	495	32	
20%	4,5,7,8	911	4,5,7,8	911	0	4,5,7	925	14	5,7	974	63	
30%	4,5,7,8	1,358	4,5,7,8	1,358	0	4,5,7	1,379	21	5,7	1,452	94	
40%	4,5,7,8	1,807	4,5,7,8	1,807	0	4,5,7	1,835	28	5,7	1,938	132	
50%	4,5,6,7,8	2,260	4,5,7,8	2,260	0	4,5,7	2,308	49	5,7	2,476	217	
60%	4,5,6,7,8	2,717	4,5,7,8	2,717	0	4,5,7	2,815	98	5,7	3,024	307	
70%	4,5,6,7,8	3,179	4,5,7,8	3,180	1	4,5,7	3,328	148	5,7	3,583	404	
80%	4,5,6,7,8	3,654	4,5,7,8	3,657	2	4,5,7	3,858	204	5,7	4,155	500	
90%	4,5,6,7,8	4,123	4,5,7,8	4,126	3	5,7,8	4,415	291	5,7	4,717	593	

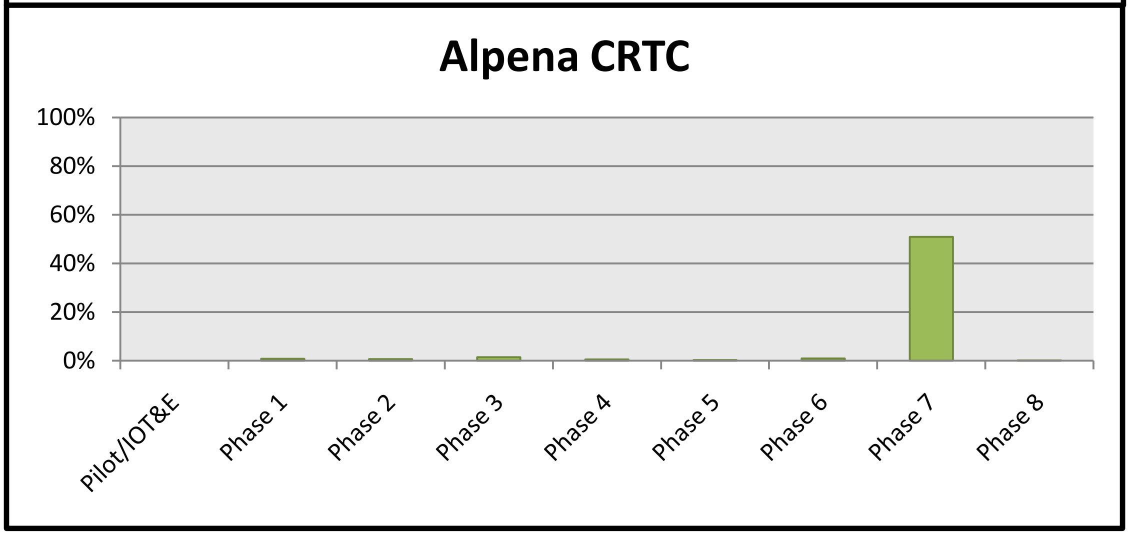
1 Location Max		
Locations*	Cost ($000)	Δ ($000)
5	543	80
5	1,068	158
7	1,851	494
7	2,464	658
7	3,077	818
7	3,680	964
7	4,288	1,109
7	4,903	1,249
7	5,510	1,386

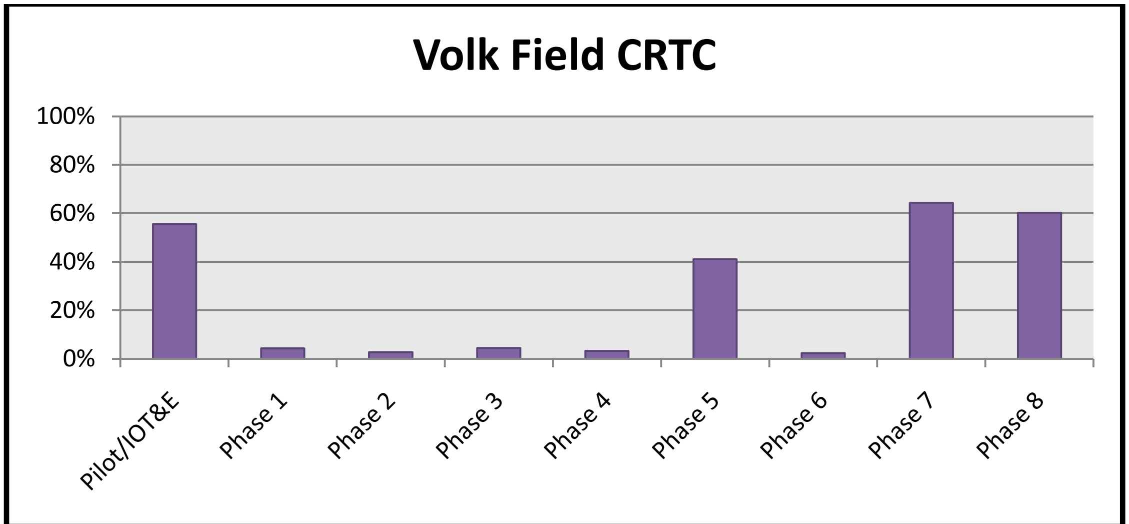
* Supply Locations: 1- Gulfport 2- Savannah, 3- Alpena, 4- Volk Field, 5- Hill, 6- Hanscom, 7- Tinker, 8- Robins

Appendix L: Frequency within Optimal Solutions by Base





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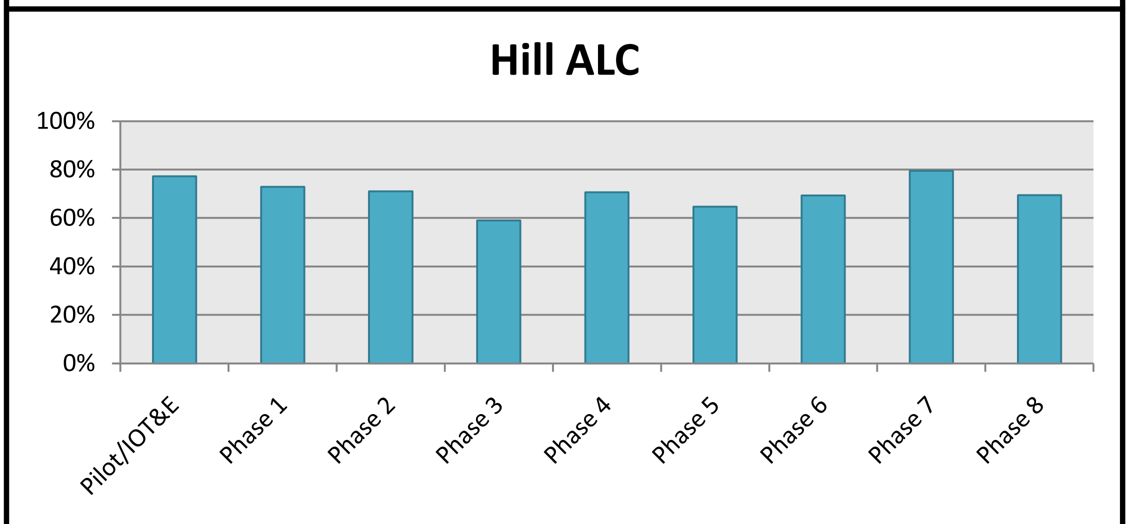
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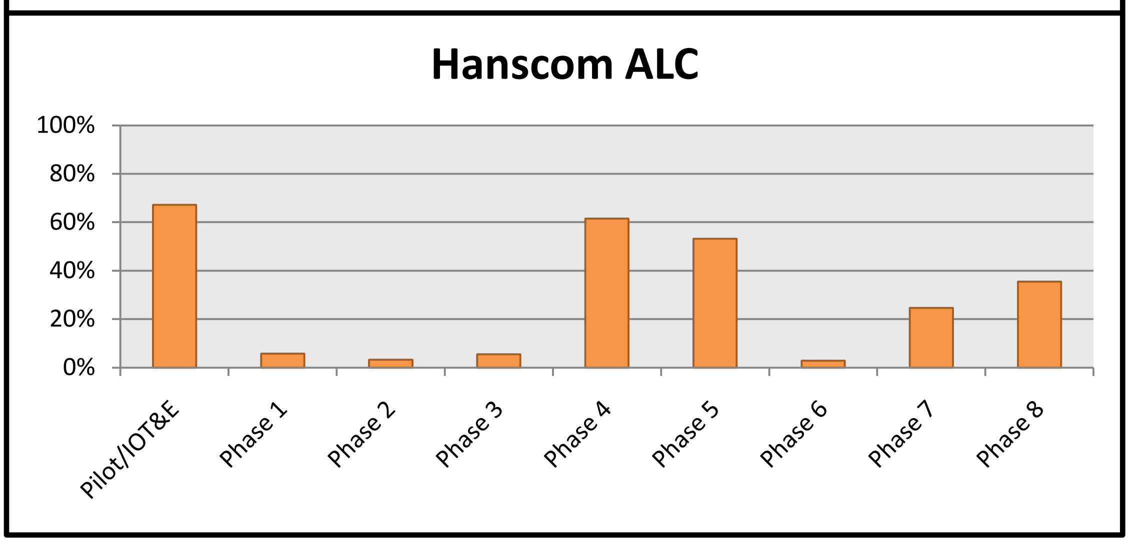
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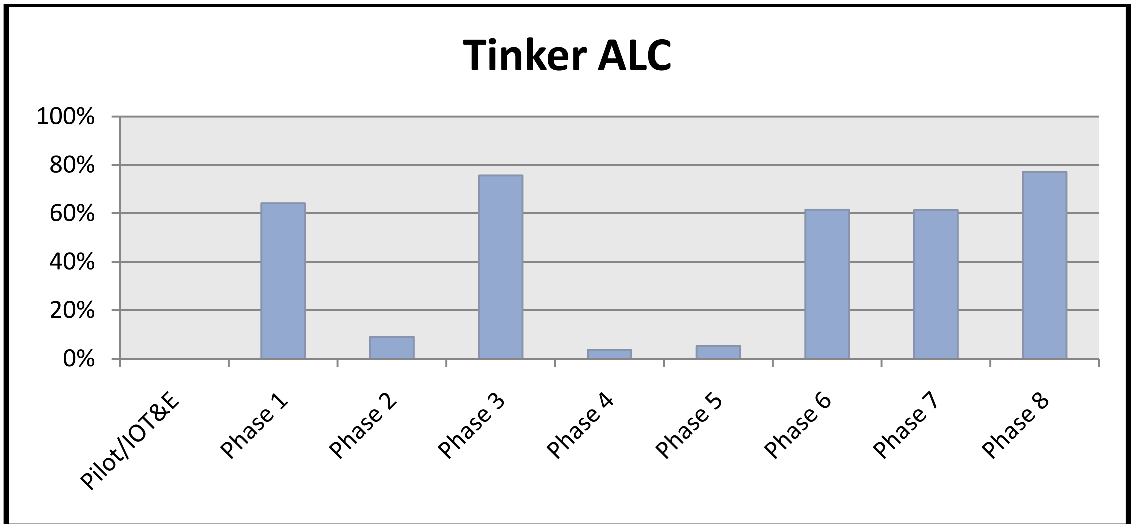
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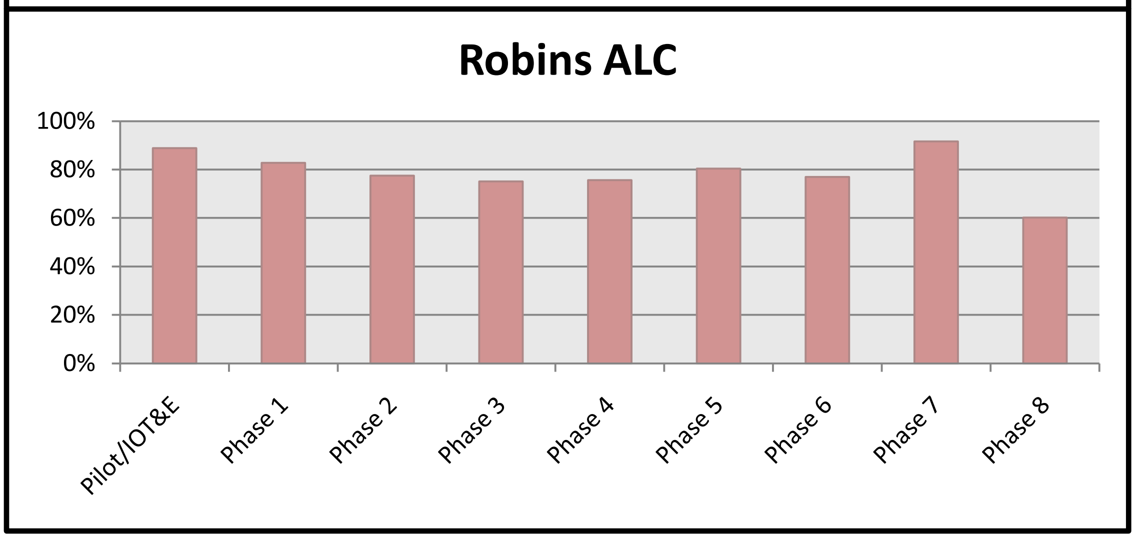
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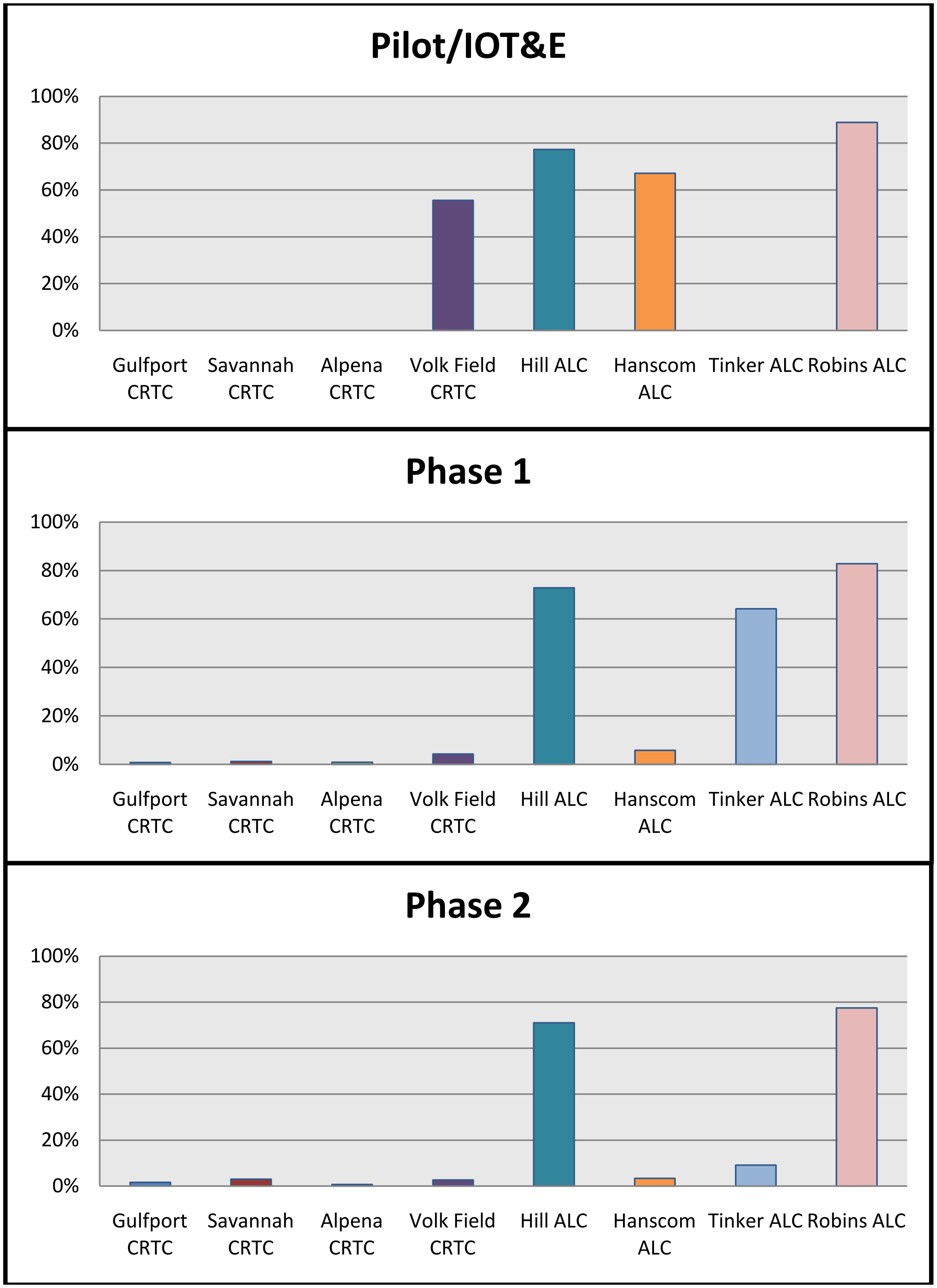
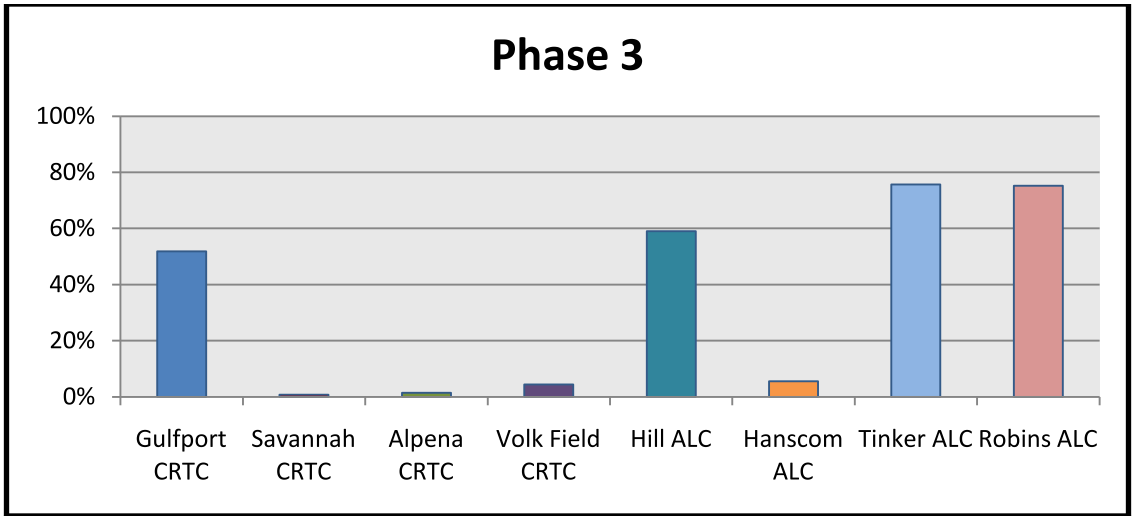
Phase 8

Appendix M: Frequency within Optimal Solutions by Phase

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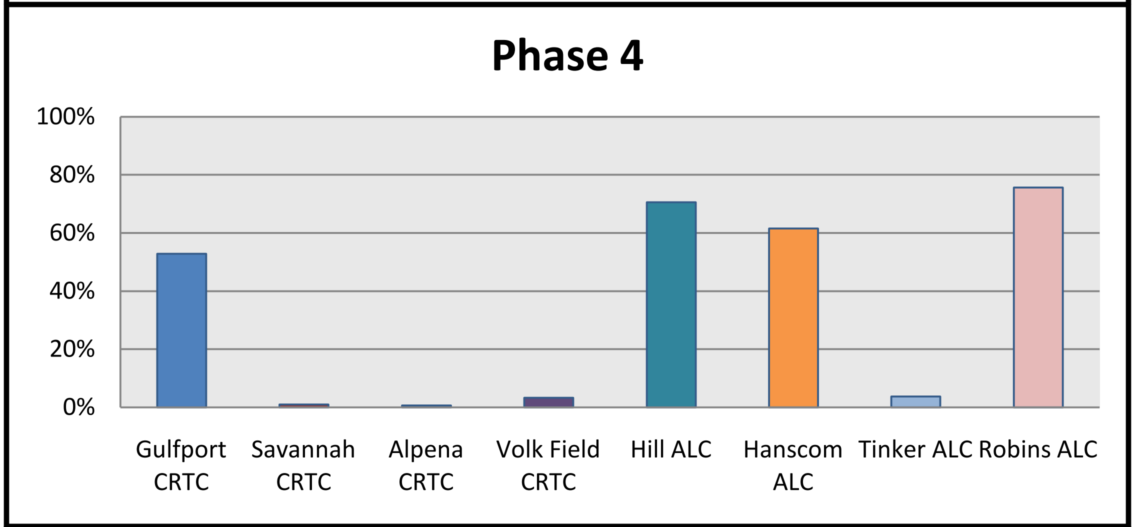
Tinker ALC
Robins ALC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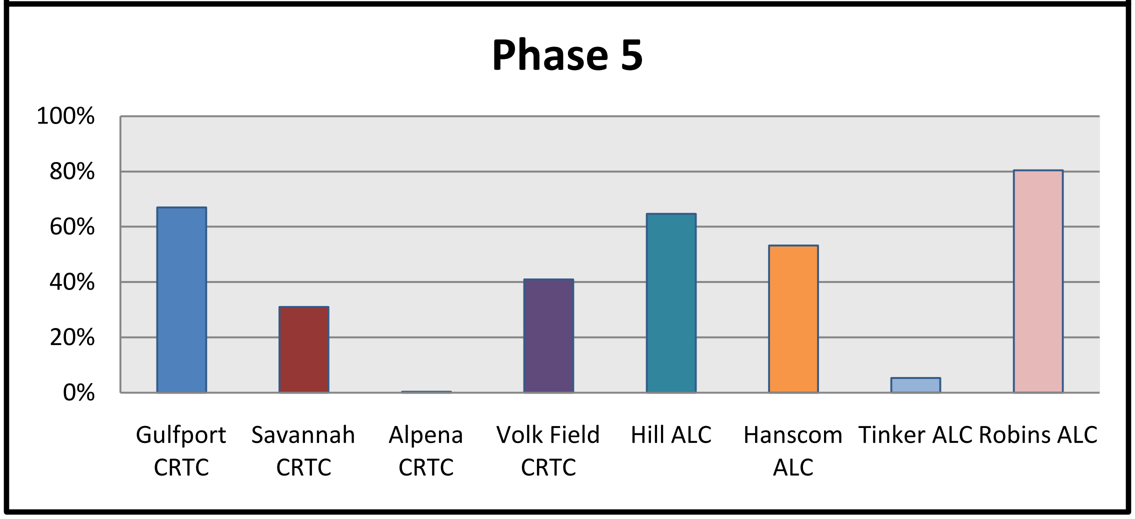
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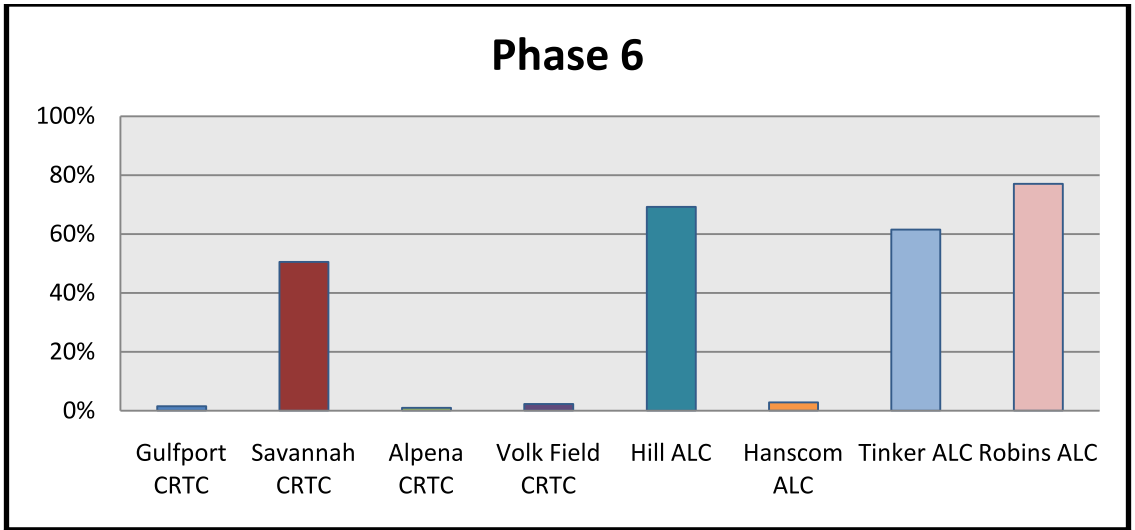
Robins ALC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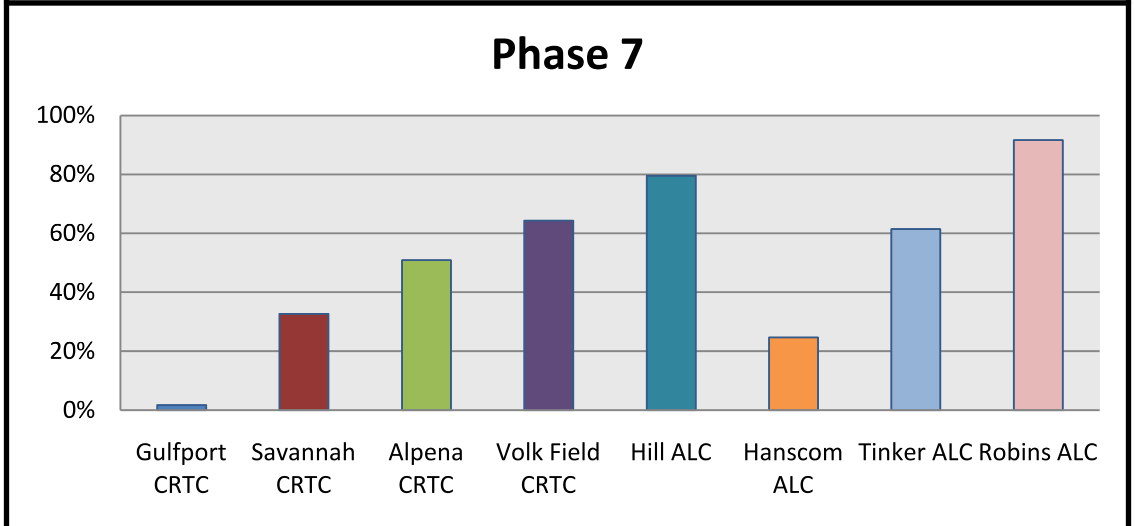
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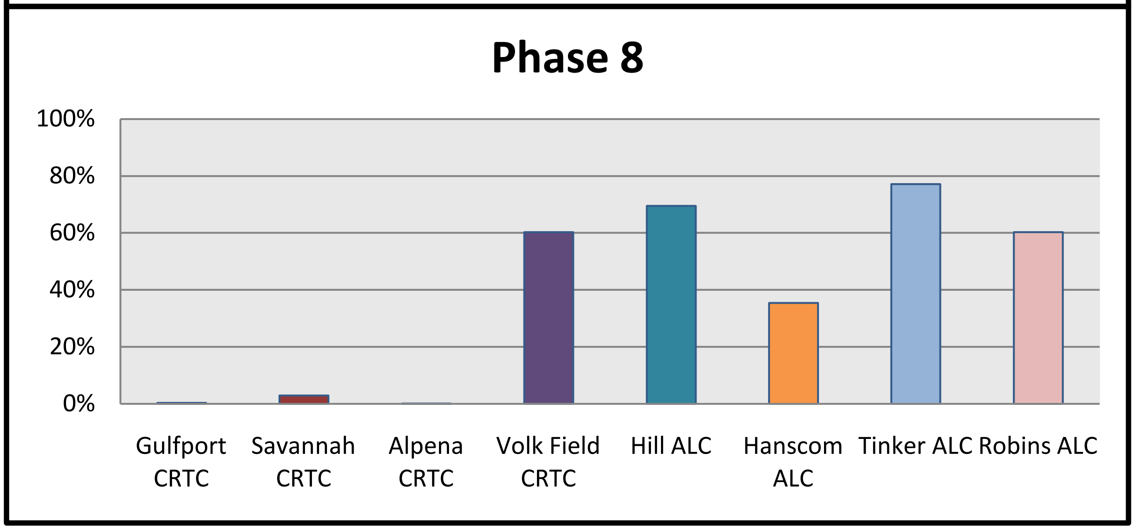
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Hill ALC
Hanscom ALC
Tinker ALC
Robins ALC

Appendix N: Blue Dart

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Word Count: 572

Saving Millions of Dollars with Travel Cost Minimizing Training Locations

In recent years, the Department of Defense (DoD) has spent an average of more than $1.25 billion annually on personnel travel. This large recurring travel expense creates strain on the Department's already tight budget but is seemingly unavoidable; DoD employees must travel, and travel costs money.

Efforts have been made, in the way of government-contracted airfares, to reduce the fiscal burden travel places on the DoD budget, but a high volume of travelers still creates a heavy price tag each year. Fortunately, a means to cut these travel expenses, without reducing the number of travelers, does exist.

Per diem rates and the cost of airfare vary significantly from location to location, which means that some travel destinations are more expensive than others. Therefore, by choosing to accomplish missions, such as training, at destinations that minimize travel expenses, it is presumable that the DoD can potentially reduce its annual spending on travel. To test this presumption, I examine the impact potential training locations for the Air Force logistics' new Expeditionary Combat Support System (ECSS) have on overall travel costs.

ECSS is a web-based computer system that consolidates Air Force Logistics' business functions in order to create transparency across the entire organization. This transparency allows for improved communication between functions and provides Air

Force decision makers the means to allocate its resources more efficiently. As a necessarily robust system, ECSS demands more than 250,000 end-users receive training on how to operate the system. This training requirement increases travel costs to the Air Force, as many ECSS end-users must attend training away from their home station.

Currently, eight locations are being considered to provide a significant portion of the ECSS end-user training; however, each location results in a different average travel expense. In other words, some training locations are more expensive to travel to than others because of their higher required airfares and per diem rates.

Knowing these potential differences that training locations have on overall travel expenses, I use an optimization technique known as linear programming to determine which of the eight potential training locations mentioned above result in the lowest overall travel costs and thus reduce the ECSS implementation's impact on the Air Force's constrained budget. In addition, I determine the travel costs associated with selecting the worst training locations to estimate how much the optimal training locations can reduce travel expenses.

The findings of my research are remarkable. Sending approximately 37,000 ECSS end-users to the optimal training locations determined using my linear programming model results in overall travel costs that are an estimated $39.4 million less than sending the same end-users to the worst training locations. This large difference in potential travel costs is especially alarming when we consider that my research focuses on less than 40,000 end-users and a maximum of eight potential training bases, while the DoD trains hundreds of thousands of individuals across dozens of bases each year.

If location selection in my ECSS research example can result in a travel cost difference of nearly $40 million, it is reasonable to assume that even larger differences exist when more travelers and more destinations are considered. Therefore, further research should expand on my efforts and focus on determining locations beyond the ECSS training context that can minimize travel costs. Doing so could undoubtedly result in travel cost savings of tens or hundreds of millions of dollars across the DoD.

Jason Boerboom is a student at the Air Force Institute of Technology

The views expressed in this article are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States Government.

Bibliography

Ahuja, Ravindra K., Thomas L. Magnanti, and James B. Orlin. *Network Flows: Theory, Algorithms, and Applications.* Englewood Cliffs NJ: Prentice-Hall, 1993.

Baker III, Fred W. "Gates Seeks to Shift Thinking on Budget, War." Excerpt from unpublished article dated 17 April 2009. n. pag. http://www.maxwell.af.mil/news. 22 September 2009.

Bayer, Michael J. and others. "Focusing a Transition: A Report By The Defense Business Board." Report to the Secretary of Defense, The Pentagon, Washington DC. January 2009.

Bertsekas, Dimitri P. *Linear Network Optimization: Algorithms and Codes.* Cambridge MA: The MIT Press, 1991.

Bertsekas, Dimitri P. *Network Optimization: Continuous and Discrete Models.* Belmont, MA: Athena Scientific, 1998.

Brandimarte, Paolo and Giulio Zotteri. *Introduction to Distribution Logistics.* Hoboken NJ: John Wiley & Sons, 2007.

Cain, Steven L. "The Logistics Transformation Office," *Air Force Journal of Logistics,* 31: 34-38 (Summer 2007).

Computer Sciences Corporation (CSC). "Draft End Users Training Plan: Version 2.0." Beavercreek OH, 2009.

Dantzig, George B. and Mukund N. Thapa. *Linear Programming 2: Theory and Extensions.* New York: Springer-Verlag, 1997.

Dantzig, George B. "Linear Programming," *Operations Research,* 50, 42-47 (January 2002).

Defense Travel Management Office (DTMO). "Defense Travel System: Document Processing Manual." Version 1.3.25, 2009. http://www.defensetravel.dod.mil/Training/DTS/TrnMat.cfm

Department of the Air Force. "Expeditionary Logistics for the 21st Century Campaign Plan." Washington DC, 2008. 22 September 2009. http://www.af.mil/shared/media/document/AFD-060831-041.pdf

Department of the Air Force. "FY 2010 Budget Estimates May 2009: Operation and Maintenance, Air Force Overview Exhibits." Washington DC, 2009. 22 September 2009. http://www.saffm.hq.af.mil/budget.

Department of the Air Force. “FY 2011 Budget Estimates February 2010: Operation and Maintenance, Air Force Volume 1.” Washington DC, 2010. 12 February 2010. http://www.saffm.hq.af.mil/budget.

Surface Deployment and Distribution Command (SDDC). “Electronic Transportation Acquisition.” n. pag. 16 November 2009. https://eta.sddc.army.mil.

Expeditionary Combat Support System (ECSS). http://www.ecssmission.com. 22 September 2009.

Florian, Michael and Denis Lebeuf. ”An Efficient Implementation of the Network Simplex Method,” in *Network Optimization*. Ed. Panos M. Pardalos, Donald W. Hearn and William W. Hager. Berlin: Springer-Verlag, 1997.

Fylstra, Daniel, Leon Lasdon, John Watson and Allan Waren. “Design and Use of Microsoft Excel Solver,” *Interfaces,* 28: 29-55 (September 1998).

Government Accountability Office (GAO). *Air Force Operating and Support Cost Reductions Need Higher Priority.* Washington DC: Government Printing Office. GAO/NSIAD- 00-165. August 2000.

General Services Administration (GSA). “Airfares (City Pair Program).” n. pag. http://www.gsa.gov/. 22 September 2009.

Hammer, Michael and James Champy. *Reengineering the Corporation: A Manifesto for Business Revolution.* New York: HarperCollins Publishers, 1993.

Hartman, Paul. “ECSS Change Management,” *Air Force Journal of Logistics*, 31: 24-27 (Summer 2007).

Hillier, Frederick S. and Gerald J. Lieberman. *Introduction to Operations Research.* (4th Edition). Oakland CA: Holden-Day, 1986.

Jensen, Paul A. and J. Wesley Barnes. *Network Flow Programming.* New York: John Wiley & Sons, 1980.

Kelly, Damian J. and Garrett M. O’Neill. *The Minimum Cost Flow Problem and The Network Simplex Solution Method.* MS dissertation. University College Dublin - National University of Ireland, Dublin, September 1991.

Luenberger, David G. *Linear and Nonlinear Programming* (2nd Edition). Reading, MA: Addison-Wesley Publishing Company, 1984.

Microsoft Corporation. “Microsoft Office Excel.” Product information. n. pag. 16 January 2010. http://office.microsoft.com/en-us/excel/default.aspx.

Morse, Philip M. and George E. Kimball. *Methods of Operations Research.* Mineola NY: Dover Publications, 2003.

Oracle Corporation. "Oracle E-Business Suite." Product description. 22 September 2009. http://www.oracle.com/us/products/applications/ebusiness/index.htm

Per Diem, Travel and Transportation Allowance Committee, The (PDTATAC). *The Joint Federal Travel Regulations*. Volume 1. U3005. Arlington VA, 1 June 2009. http://www.defensetravel.dod.mil.

Pike, Ralph W. *Optimization for Engineering Systems.* Louisiana State University: Minerals Processing Research Institute, 2001. 10 November 2009. http://www.mpri.lsu.edu/bookindex.html.

Ragsdale, Cliff T. *Spreadsheet Modeling & Decision Analysis: A Practical Introduction to Management Science* (5th Edition). Mason OH: Thomas South-Western, 2007.

Rumsfeld, Donald H. Secretary of Defense. "Bureaucracy to Battlefield." Remarks during the DOD Acquisition and Logistics Excellence Week Kickoff. The Pentagon, Arlington VA. 10 September 2001.

Sharma, J.K. "Extensions and Special Cases of Transportation Problem: A Survey," *Indian Journal of Pure and Applied Mathematics,* 9: 928-940 (September 1978).

Spencer, Larry O. *United States Air Force FY 2010 Budget Overview*. Washington: SAF/FMB, 2009. 22 September 2009. http://www.saffm.hq.af.mil/budget.

Sprague, Thomas M. *Education and Training as Part of an Expeditionary Combat Support System Implementation Strategy.* MS thesis. AFIT/GLM/ENS/09-10. School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2009 (ADA500355).

Todd, Michael J. "The Many Facets of Linear Programming," *Mathematical Programming*, 91: 417-436 (February 2002).

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14. ABSTRACT

The Department of Defense is currently operating in a fiscally constrained environment, and Air Force leaders are pressured to minimize spending while pursuing mission critical objectives. Personnel travel usurps a significant portion of the Air Force's annual operations and maintenance (O&M) budget each year, but receives little attention with respect to cost saving strategies. During the Air Force's implementation of the Expeditionary Combat Support System (ECSS), in which over 250,000 end-users will require training, it is vital that the Department determine the training locations that minimize costs incurred through personnel travel. This thesis seeks to determine which potential ECSS training locations minimize travel costs, and thus reduce the system implementation's impact on the Air Force's constrained O&M budget. Airfare and per diem rates vary significantly depending on the travel destination, which naturally makes some potential training locations more costly, with respect to travel expenses, than others. In this research, the findings indicate that using a linear programming approach to identify the optimal ECSS training locations can potentially reduce overall travel costs from 80% to more than 130%. Furthermore, the research findings indicate that the Air Logistics Centers located at Robins, Hill, Hanscom and Tinker are likely to minimize travel costs for ECSS training if the supply, or training capacity, at these locations can satisfy the demand for training.

15. SUBJECT TERMS
Linear Programming, Expeditionary Combat Support System, ECSS, Cost Minimization, Training Location

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